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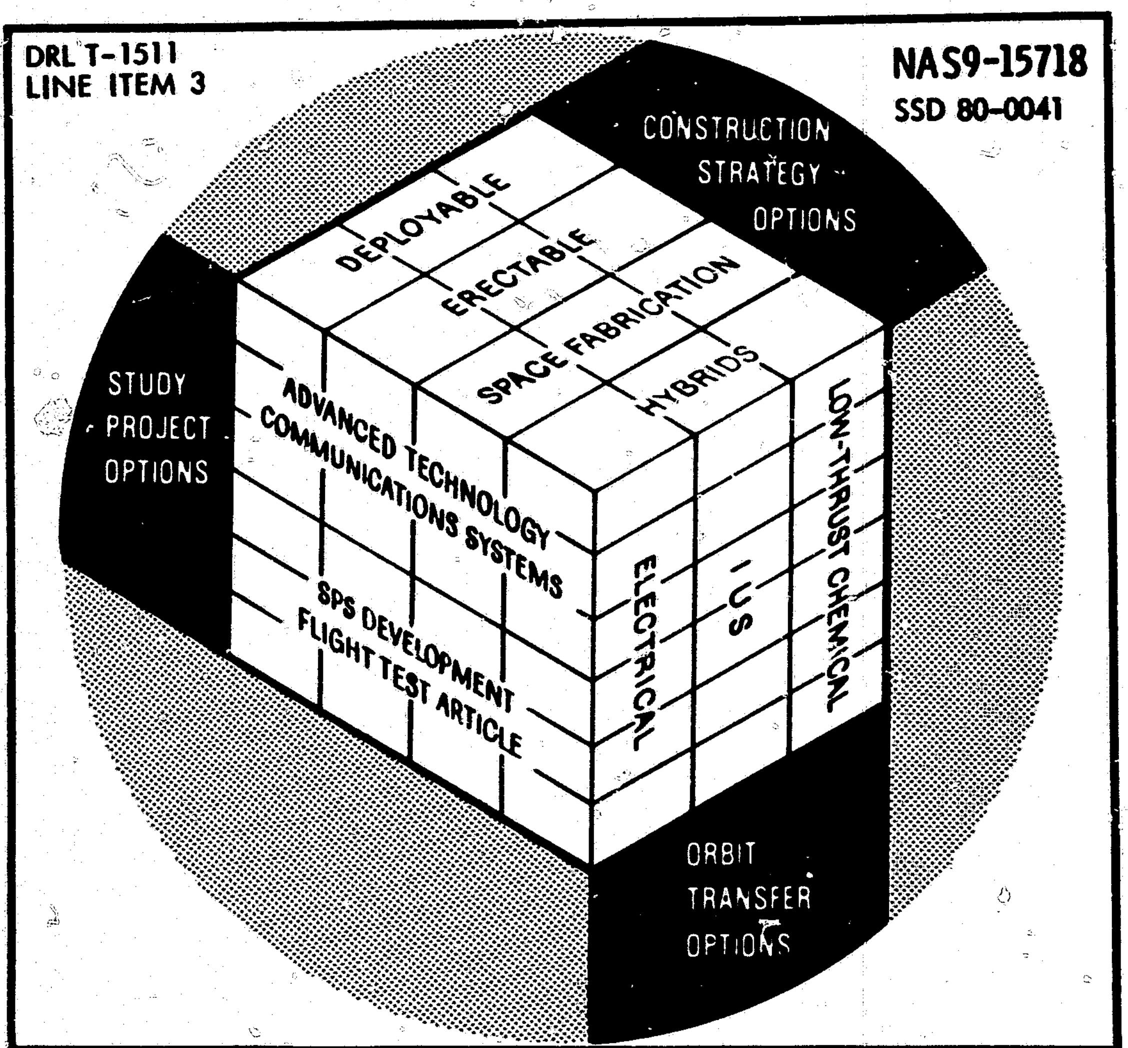

SPACE CONSTRUCTION SYSTEM ANALYSIS

PART 2 FINAL REPORT EXECUTIVE SUMMARY

JUNE 1980

Rockwell International
Space Operations and
Satellite Systems Division
Space Systems Group
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Downey, CA 90241

FOREWORD

In September 1979, NASA/JSC awarded the subject contract, Space Construction System Analysis (NAS9-15718) to the Space Systems Group of Rockwell International. The contract included two serial parts, each nine months in duration. The first part was summarized in July 1979: Final Review, Part I, Executive Summary, Rockwell Report PD 79-18. This report is an executive summary of Part II.

The study was administered under the technical direction of the Contracting Officer's Representative, Mr. Sam Nassiff, Systems Design Office, Spacecraft Design Division, Johnson Space Center.

Rockwell's study team was led by Ellis Katz and included the following key personnel:

A. Stefan	System Design	G. Gimlich	Design
H. Myers	System Analysis	J. Roebuck	Operations Analysis
F. Von Flue	Programmatics	C. Fritz	Operations Analysis
L. Wiley	Experiment Definition	S. Greenberg	Structures
J. Boddy	Experiment Definition	R. Donavan	Communications
D. Peebles	Design	J. Indrikis	Flight Performance
R. Hart	Design	P. DeJong	Electrical Power
R. Thompson	Design	J. Jandrasi	Electrical Power
P. Buck	Design	R. Abramson	Guidance and Control
A. LeFever	Design	M. Manoff	Thermal Control
M. Vocka	Design	C. McBaine	Weights

OBJECTIVES, PART II

The key objective of Part II was to perform a detailed end-to-end analysis of the activities, techniques, equipment, and Shuttle provisions required to construct a reference project system. Although earlier government and industry-funded studies have investigated space construction methods and concepts, none had been conducted to the detail required by the objectives, as listed, of this study.

The listed study objectives were achieved - this report summarizes the major accomplishments of the study. Details of the study have been reported in the following documentation:

- SSD 80-0037, SCSA Part 2 Report, Platform Definition
- SSD 80-0038, SCSA Part 2 Report, Construction Analysis
- SSD 80-0039, SCSA Part 2 Report, Cost and Programmatics
- SSD 80-0040, SCSA Part 2 Report, Space Construction Experiments Concepts

OBJECTIVES—PART II

- PERFORM END-TO-END CONSTRUCTION ANALYSIS FOR A REFERENCE LARGE SPACE PROJECT SYSTEM
- DETERMINE CONSTRUCTION DRIVERS
- DETERMINE CONSTRUCTION SUPPORT EQUIPMENT REQUIREMENTS
- DETERMINE ORBITER SUPPORT AND MODIFICATION REQUIREMENTS
- DEFINE THE TECHNOLOGY NEEDS AND A DEVELOPMENT PLAN TO IMPLEMENT THE SPACE CONSTRUCTION OF THE PROJECT SYSTEM
- IDENTIFY FLIGHT EXPERIMENT CONCEPTS APPROPRIATE TO THE DEVELOPMENT OF THE SPACE CONSTRUCTION TECHNOLOGY

STUDY APPROACH

Part II of the study was initiated June 1979 and concluded in March 1980.

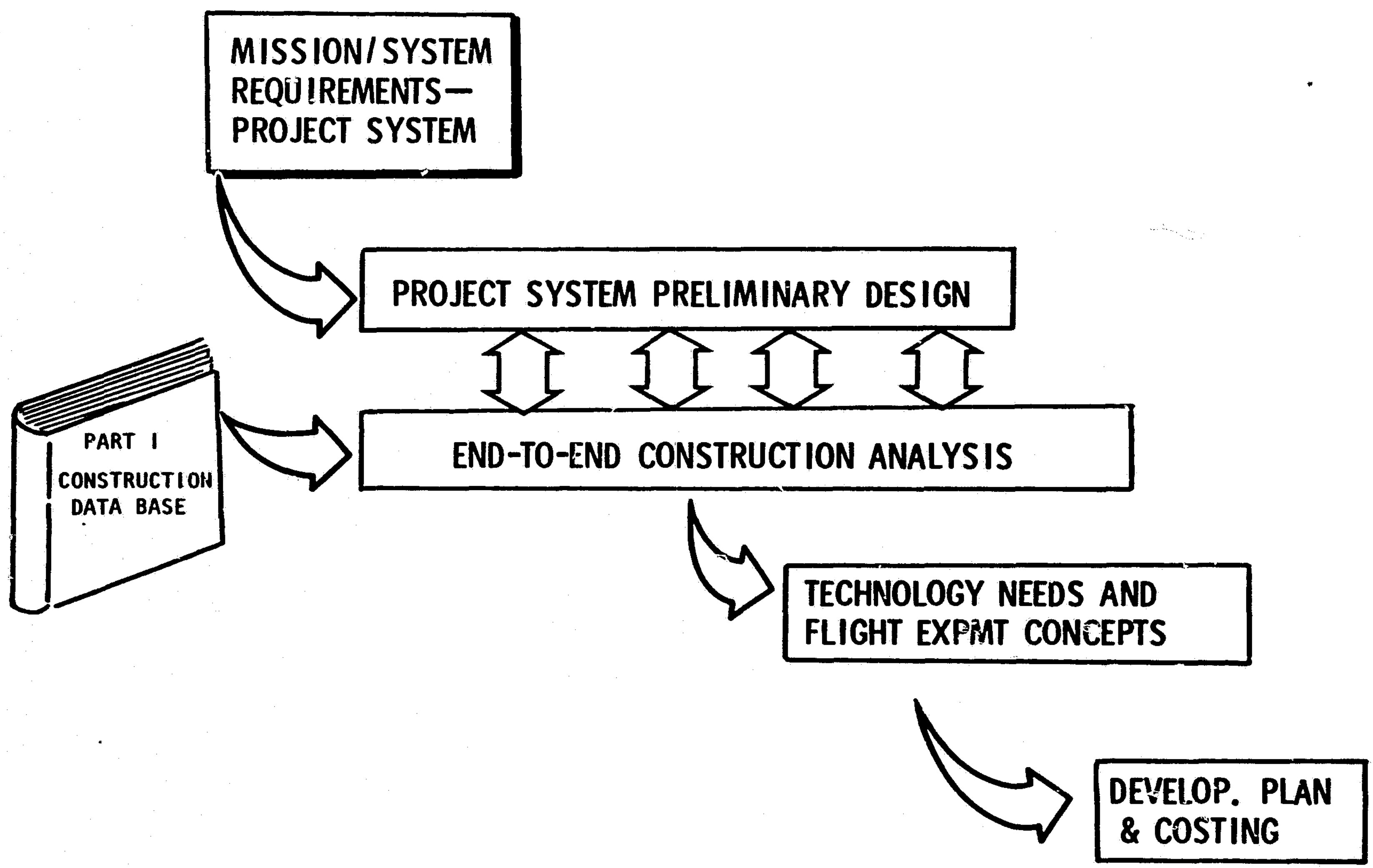
The initial activity centered on estalishing mission requirements and concepts for an "Engineering and Technology Verification Platform" (ETVP). This platform (described later) was selected to represent a future system which would drive out most of the construction requirements forseeable through the decade of the 90's.

A configuration concept for the ETVP was selected in July 1979, and parallel tasks commenced for preliminary design and construction analyses. As indicated, these two tasks were carried out interactively throughout most of the study. The Construction Methods Data Base from Part I served as an important resource for the construction analysis task.

A mid-term review was held at JSC and at NASA Headquarters in October 1979 and November 1979, and the contract was expanded to include definition of early Shuttle flight experiment concepts.

The construction analysis task was concluded with detailed analyses of timelines, crew duty cycles, integrated lighting and power requirements, cargo manifests, cargo bay packaging and Shuttle launch requirements, and an overall analysis of construction drivers. This effort also enabled the determination of requirements for early Shuttle flight experiments and for development planning and costing of the project construction.

STUDY APPROACH



ETVP MISSION SCENARIO

Two mission concepts, Communications Development and SPS Development, for the Engineering and Technology Verification Platform were identified.

The platform was invisioned as a space "test bed" for the development of large platform technologies and prototype payloads and mission hardware in the late 80's time period. It was considered that the activities of constructing the platform, of servicing it in low and high orbits, and of transfering it between orbits would be the culmination and validation of the constituent technologies required for subsequent operational systems.

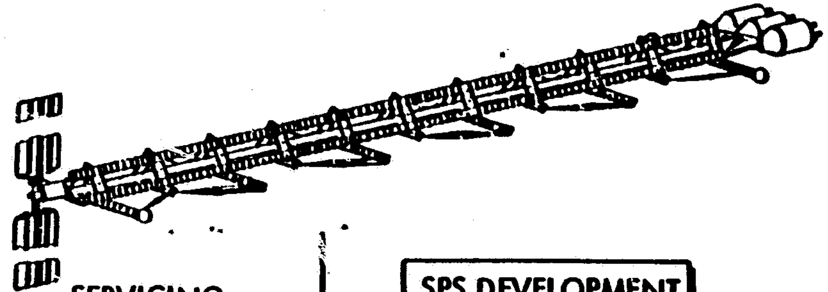
As noted, the subject platform concept was oriented to support the development of advanced communications and SPS missions and payloads.

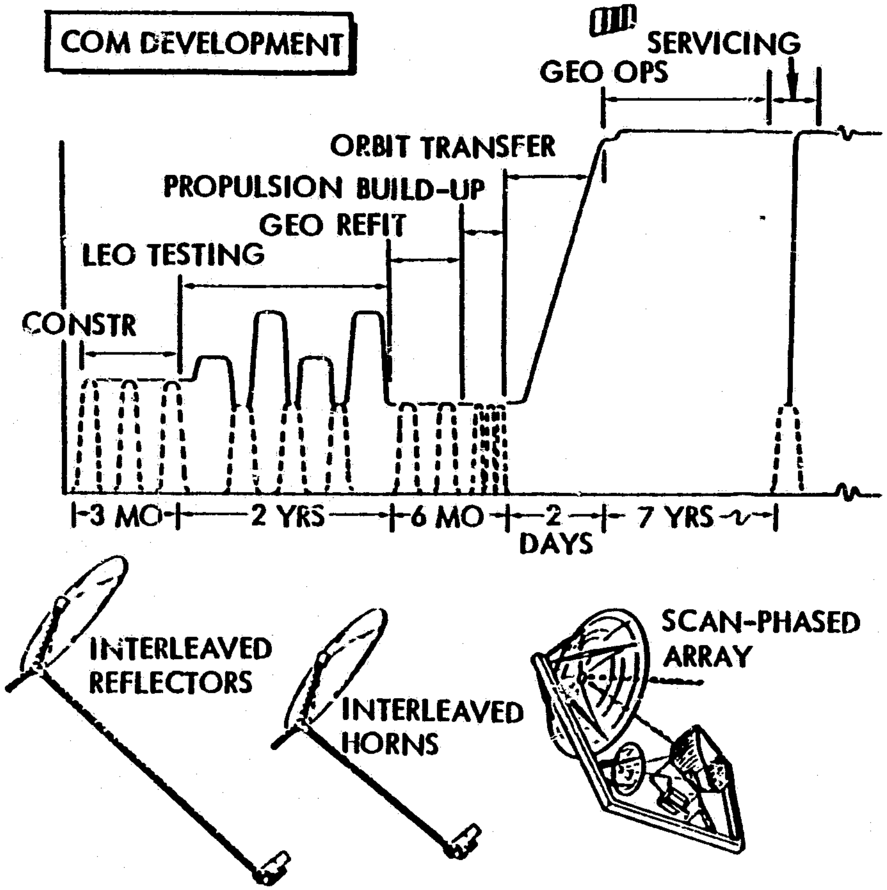
In order to establish a set of rational requirements for the communications version of the platform, a series of contacts and visits were made with space communications users and suppliers - including AT&T, COMSAT, Western Union, GE, and Collins/Rockwell. The results of these contacts led to the identification of several advanced types of multi-beam antenna systems which would be tested in low and, subsequently, in geosynchronous orbit.

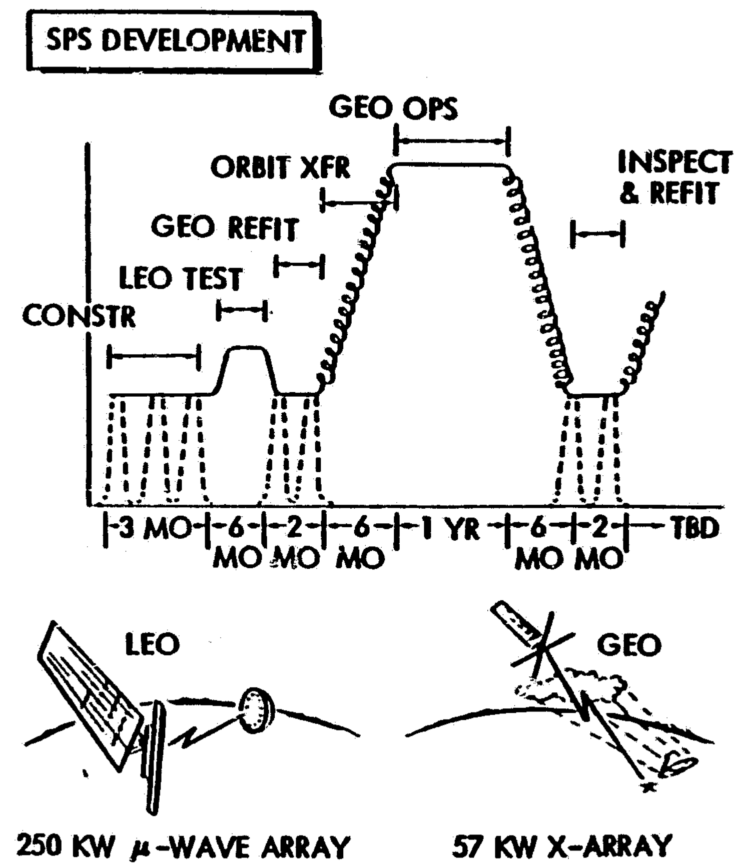
The SPS test version of the platform was configured to validate power transmission from a 4,000 square meter solar cell surface through a space - space μ-wave test antenna at low orbit and, subsequently, a space-ground test antenna at geosynch orbit.

ETVP MISSION SCENARIO

- CONSTRUCTION TECHNOLOGY
- SERVICING TECHNOLOGY
- ORBIT XFR TECHNOLOGY







The platform is shown here in a representative communications configuration.

The platform's structure is formed by three space-fabricated longitudinal beams in a "linear" arrangement. This "linear" configuration has been shown (in Part I) to be advantageous in terms of "constructability" and support equipment.

The platform's length was driven by the desire to accommodate up to eight independently mounted antennas of up to 20 m diameter. Its height (depth) was sized by the need to provide sufficient stiffness against bending/torsion loads - and by the reach of the RMS (Remote Manipulator System) arm for construction.

The transverse beams are lap-joined at intervals to the space-fabricated longitudinal beams; the spacing interval was set by structural criteria and RMS reach. Payloads, such as test/prototype communications antennas, are installed at the opposing ends of the long cross-beams and are stabilized by bracing struts running to the adjacent short cross-beams.

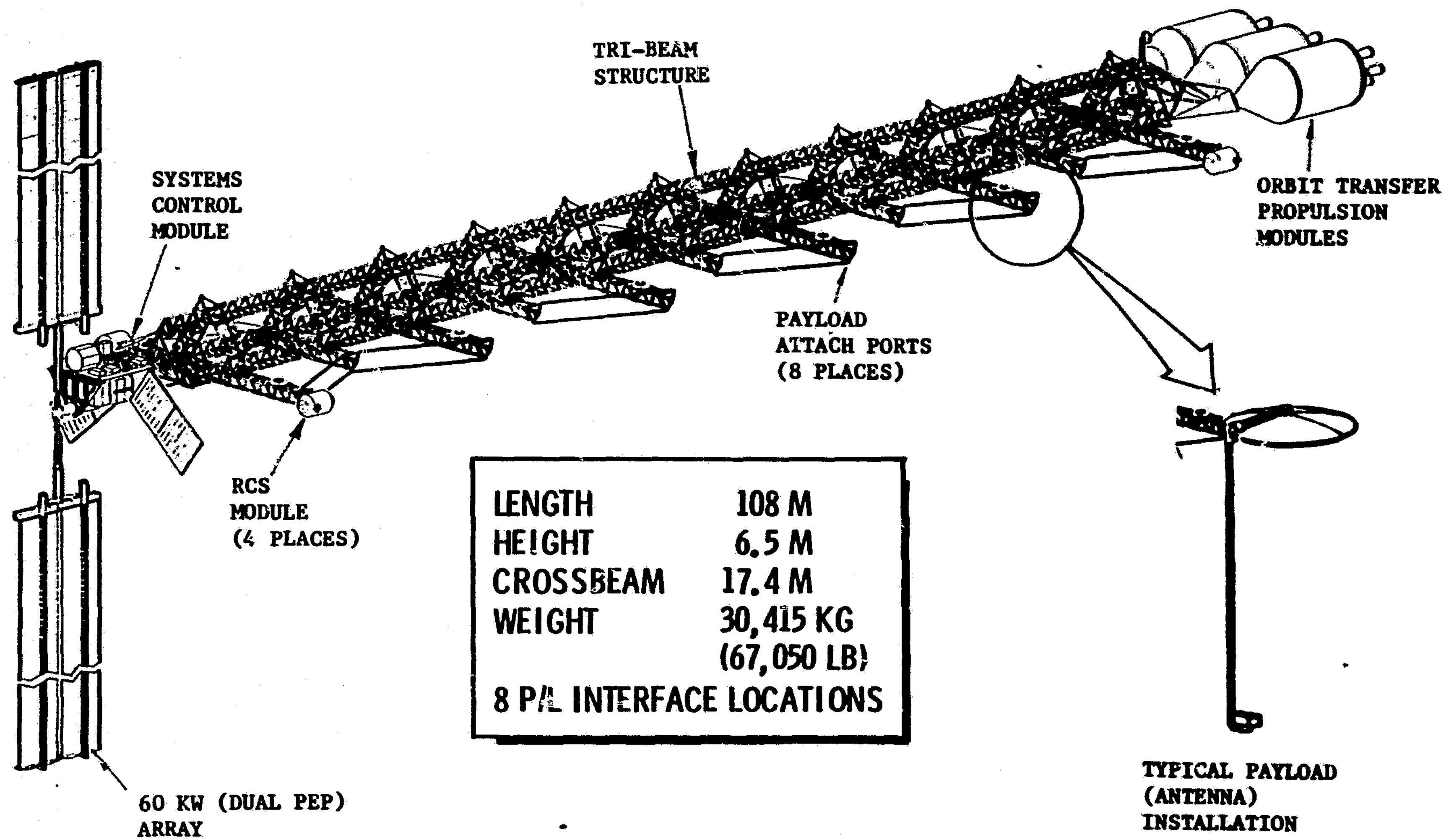
Electrical harnesses carry power and data from the System Control Module down the lower left-hand longitudinal beam, and connect with similar harnesses installed on the payload-carrying cross-beams.

The System Control Module provides power and command/control functions to the platform. The module is designed for servicing and replacement of all major components (e.g., CMG's, batteries) and, with its 60 kW solar array and radiator panels retracted, to be compactly stowed within the orbiter cargo bay. The module is supported from the main structure by a space-deployed truss; a similar truss is provided at the aft end for installation of the orbit transfer propulsion modules.

The RCS modules located at the four corners of the platform were sized to provide momentum dumping and altitude changes during low orbit testing - as well as to provide stationkeeping and control for a seven year duration at GEO. The modules were designed to be replaced at propellant exhaustion.

Three LH_2/LO_2 propulsion modules are used in a two-stage transfer to GEO. Each module, weighing 51,000 lbs. and generating 20,000 lbs. thrust, is brought up by a dedicated Shuttle in the period immediately preceeding orbit transfer.

ENGINEERING TECHNOLOGY VERIFICATION PLATFORM (ETVP)



LENGTH	108 M
HEIGHT	6.5 M
CROSSBEAM	17.4 M
WEIGHT	30,415 KG (67,050 LB)
8 P/L INTERFACE LOCATIONS	

CONSTRUCTION CONCEPTS

The following series of charts present several fundamental construction concepts which are useful to an understanding of the end-to-end construction process presented later.

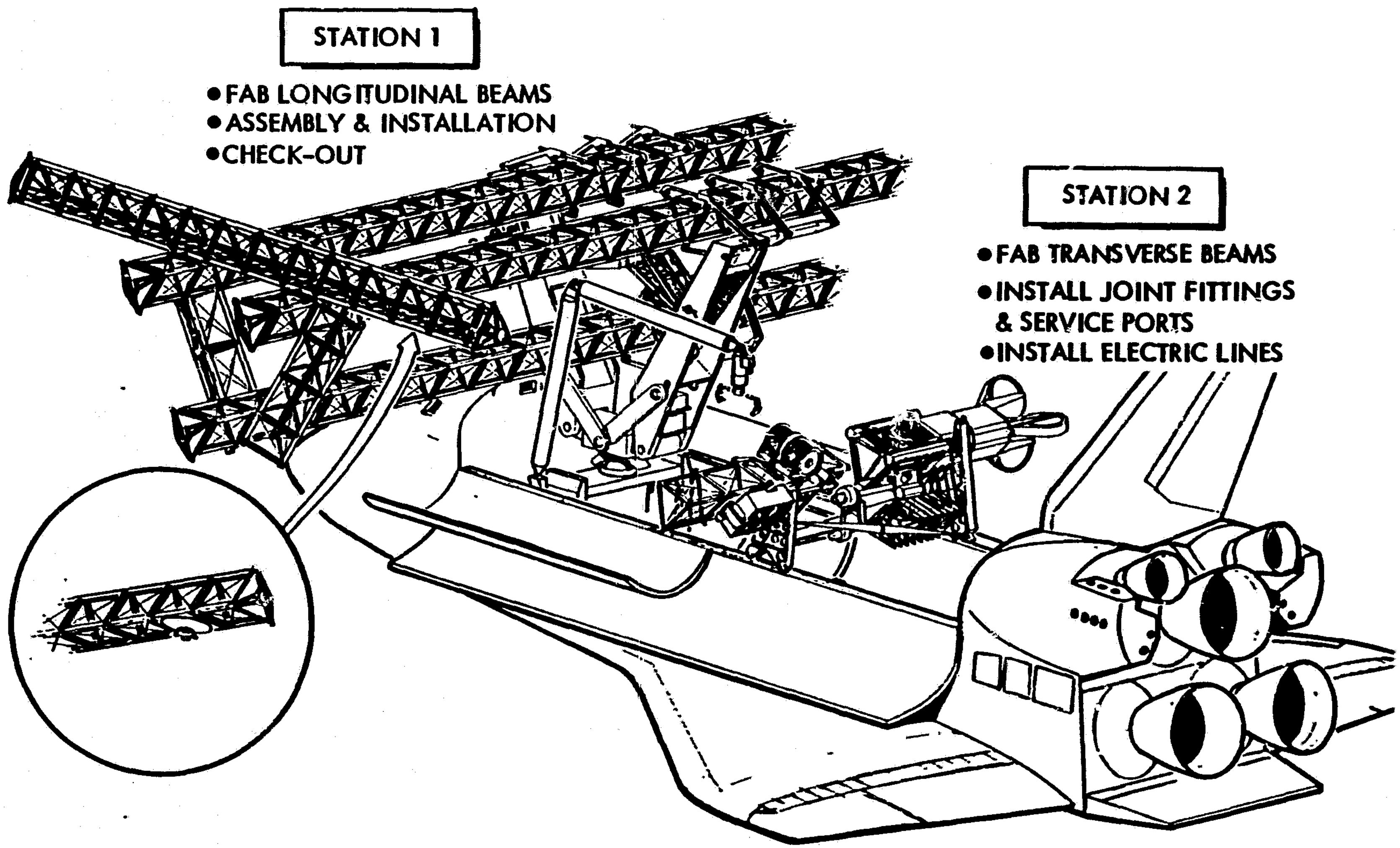
CONSTRUCTION CONCEPTS

MULTIPLE FABRICATION AND ASSEMBLY STATION CONCEPT

During Part I of the study, two basic principles of construction evolved:

1. It is beneficial to perform construction/assembly operations within a centrally located work station. This means that the platform should be constructed on or in a fixture which can translate/orient the work to the location of the work station. In the present case, it means that the platform can be two-way translated through the Station 1 fixture so that the construction operations can be performed on the fixture. The advantages of this principle are: (a) to minimize the distance/time required for moving individual parts to their installation locations; (b) to make effective utilization of the reach of the RMS; (c) to concentrate work support equipment (e.g., welding, lighting) into an integrated fixture system which can be efficiently packaged for transport.
2. It is (generally) beneficial to perform the construction in the shortest possible time. This means that construction operations should be paralleled, where practicable, and that work should be scheduled around the clock. In the present case, it means that a second work station is designed (first flight only) for fabricating the transverse beam assemblies - while, in parallel, construction operations are conducted on the main assembly at Station 1. This principle is also applied to a number of other operations too detailed to be discussed here. The advantages of this principle are: (a) to reduce the Shuttle operations charges to the project; (b) to minimize the fuel - cell cryo kit requirements for powering the orbiter and the construction equipment; (c) to increase time margin allowances for unforseen contingencies.

MULTIPLE FABRICATION AND ASSEMBLY STATION CONCEPT



EVA STATION CONCEPT

As the detailed definition of the work stations (previous chart) and associated construction activities unfolded, it became apparent that EVA should be an important operational component of the construction process.

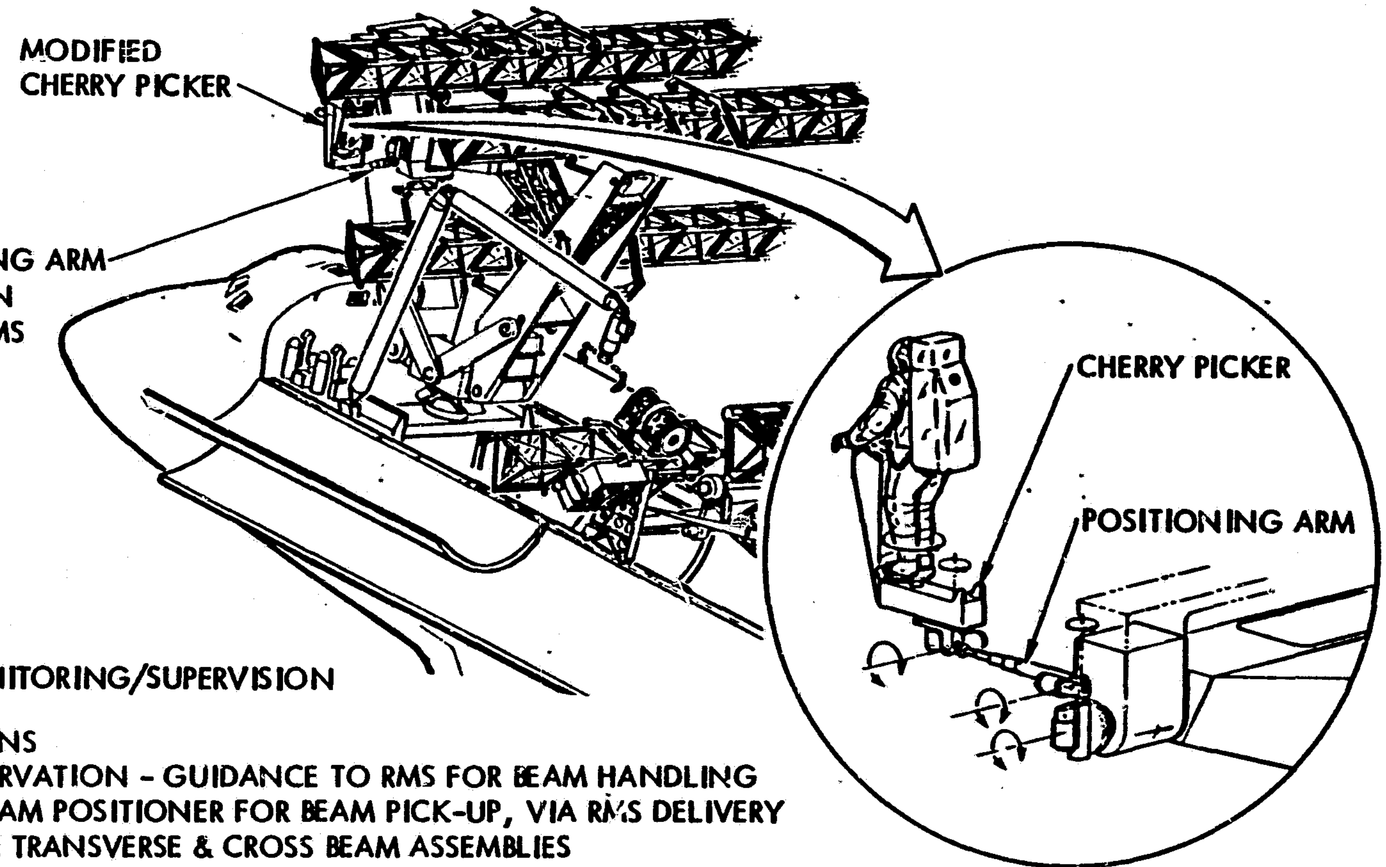
An early trade study showed the relative benefits of using EVA for enhancing the visibility and control of a number of clearance - critical operations. The nearly panoramic stereoscopic vision (with suitable illumination) available to an EVA crewman made this mode highly attractive - if not mandatory - providing that the crewman would be given the location and mobility to see.

In addition, the relative complexity of the construction support fixture and equipment (and their setups) augured for EVA as an on-site trouble-shooting/servicing capability.

Finally, it was noted that, if an EVA crewman were on-site for visibility/monitoring/trouble-shooting reasons, his value could be further enhanced if he would perform a variety of highly dexterious functions.

With the above rationale, an EVA station was designed into the main construction fixture. The station essentially consists of a modified open cherry picker mounted on a highly mobile positioning arm which provides the crewman full access to all functions listed on the chart.

EVA STATION CONCEPT



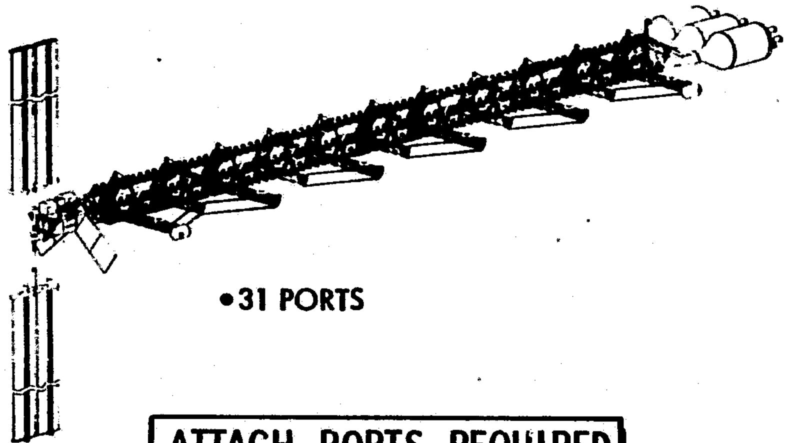
- ON-SITE MONITORING/SUPERVISION
- EVA FUNCTIONS
  - EVA OBSERVATION - GUIDANCE TO RMS FOR BEAM HANDLING
  - ALIGN BEAM POSITIONER FOR BEAM PICK-UP, VIA RMS DELIVERY
  - SUPERVISE TRANSVERSE & CROSS BEAM ASSEMBLIES
  - APPLY ELECTRODES TO SELF WELDING INTERSECTION FITTINGS
  - VERIFICATION OF STRUCTURAL INTEGRITY VIA CONTROL OF BEAM POSITIONER
  - TRANSLATE DIAGONAL CORDS BETWEEN LONGITUDINAL BEAMS
  - CONNECT TENSION CORDS TO INTERSECTION FITTINGS EARS
  - CHECK STRUCTURAL ALIGNMENT & TENSION DIAGONAL CORDS
  - RELEASE ELECT PIG TAILS FROM LONGITUDINAL & CROSS BEAMS
  - MAKE ELECTRICAL CONNECTIONS & RE-SECURE LINES

ATTACH PORT SELECTION

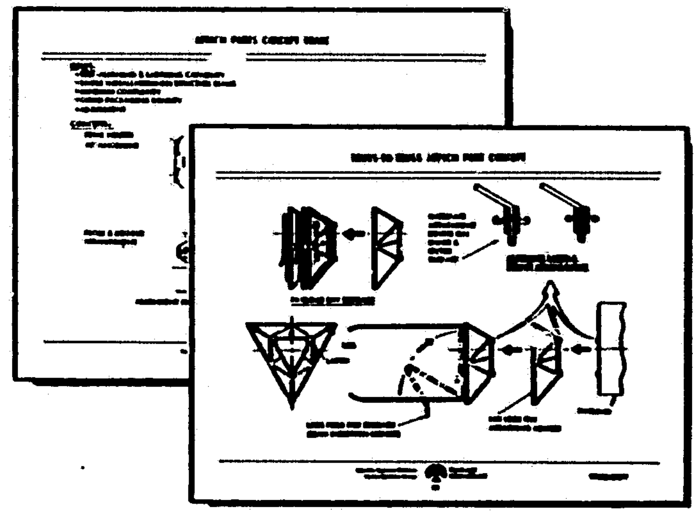
The attachment of concentrated masses such as antennas, RCS modules, etc., to the lightweight space-fabricated structure poses a special set of requirements.

A truss-type attachment port concept was developed which would distribute the concentrated inertial and dynamic loads evenly into the caps of the one meter deep cross-beams, and which would be relatively forgiving of misalignments in mating the two halves of the port in space. This port concept (in which the male and female halves are similar) was developed to provide automatic mechanical and electrical latching when mated. Furthermore, the male halves are compactly nested on mandrels for efficient packaging in the cargo bay and for mechanized feeding into the cross-beam ends during the construction process. The female halves are ground-installed on the modules and are adjusted for alignment bias as described in the following charts.

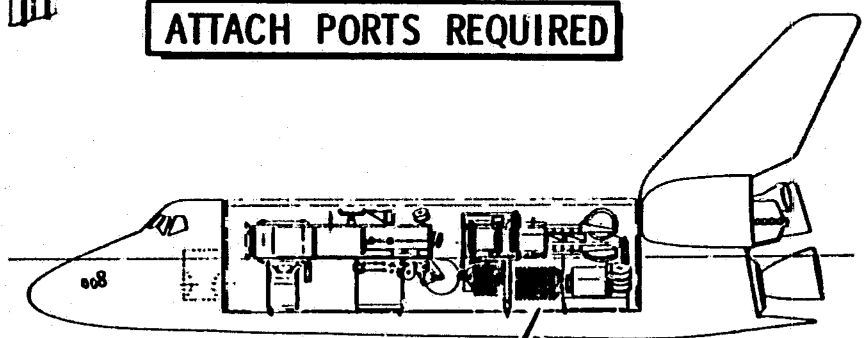
ATTACH PORT SELECTION

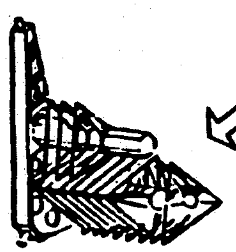


ATTACH PORTS REQUIRED

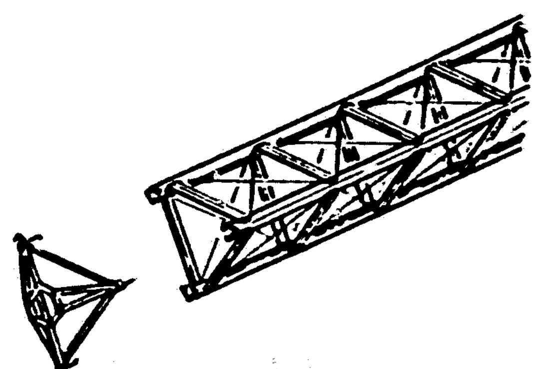


CONCEPTS EVALUATED





EFFICIENT PACKAGING



DEVELOPED CONCEPT

Six principal sources of angular misalignments between the module (e.g., antennas) attach ports and the attitude reference system located in the System Control Module (SCM) are identified.

By far, the largest source buildup is manufacturing tolerances. The major contributions to the estimate shown are: (1) misalignment between the SCM and the platform structure, and (2) twist and lateral deformation in the long (payload-carrying) cross-beams.

The remaining sources are dynamic in nature; i.e., their mean values are nearly zero over many orbits. The low value of thermal deformation (at the ports) is associated with the low thermal coefficient of expansion ($\approx 0.2 \times 10^{-6}/^{o}F$) estimated for the platform's composite structure. The attitude control source corresponds to deflections at the attach ports in reaction to RCS firings. The remaining sources of structural misalignment are trivial.

For the communications version of the platform, it is assumed that the antenna must be oriented by the platform to their ground targets to within 0.25^{o} (corresponding to roughly one beam width); antenna auto track loops would provide vernier steering of the beams by adjustment of the antenna feeds.

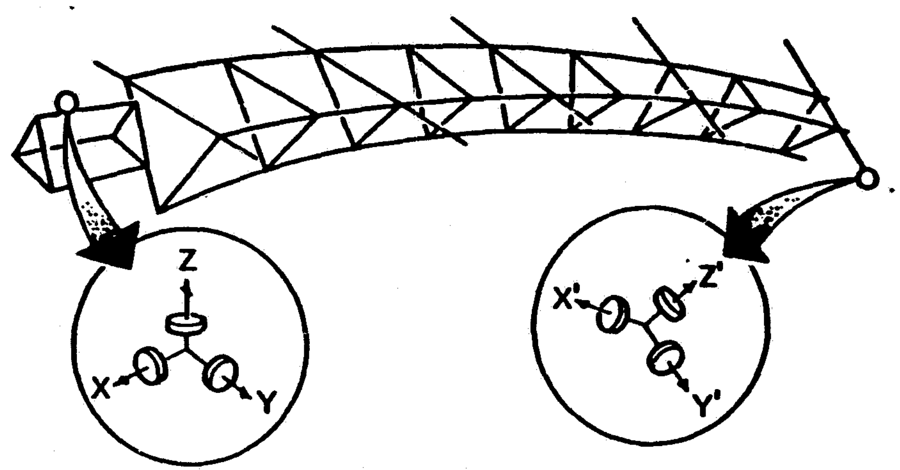
It is noted, therefore, that the antennas must be aligned to the reference axes of the SCM to well within 0.25^{o} (15 arc min). Consequently, it is necessary to compensate the built-in manufacturing error. This can be accomplished by measuring the as-constructed misalignment at each port, and providing (prior to launch) the appropriate alignment bias between the female half of the port and the antenna module to be installed. The proposed technique for measuring the misalignments is shown on the following chart.

STRUCTURAL ACCURACY

CONTRIBUTING CONDITIONS	TOLERANCES/DEFLECTIONS
• MANUFACTURING/ASSEMBLY	±1.9° AT ATTACH PORT
• THERMAL GRADIENT	1.5 $\overset{\frown}{\text{MIN}}$
• ATTITUDE CONTROL	2.6 $\overset{\frown}{\text{MIN}}$
• STATION KEEPING	.5 $\overset{\frown}{\text{MIN}}$
• GRAVITY GRADIENT	NEGLIGIBLE
• SOLAR PRESSURE	NEGLIGIBLE

PROVIDE GROUND ADJUSTMENT OF PAYLOAD PORT TO CORRECT TO ≪ ±.10°

- STRUCTURAL DEVIATION



ATTACH PORT ALIGNMENT CONCEPT

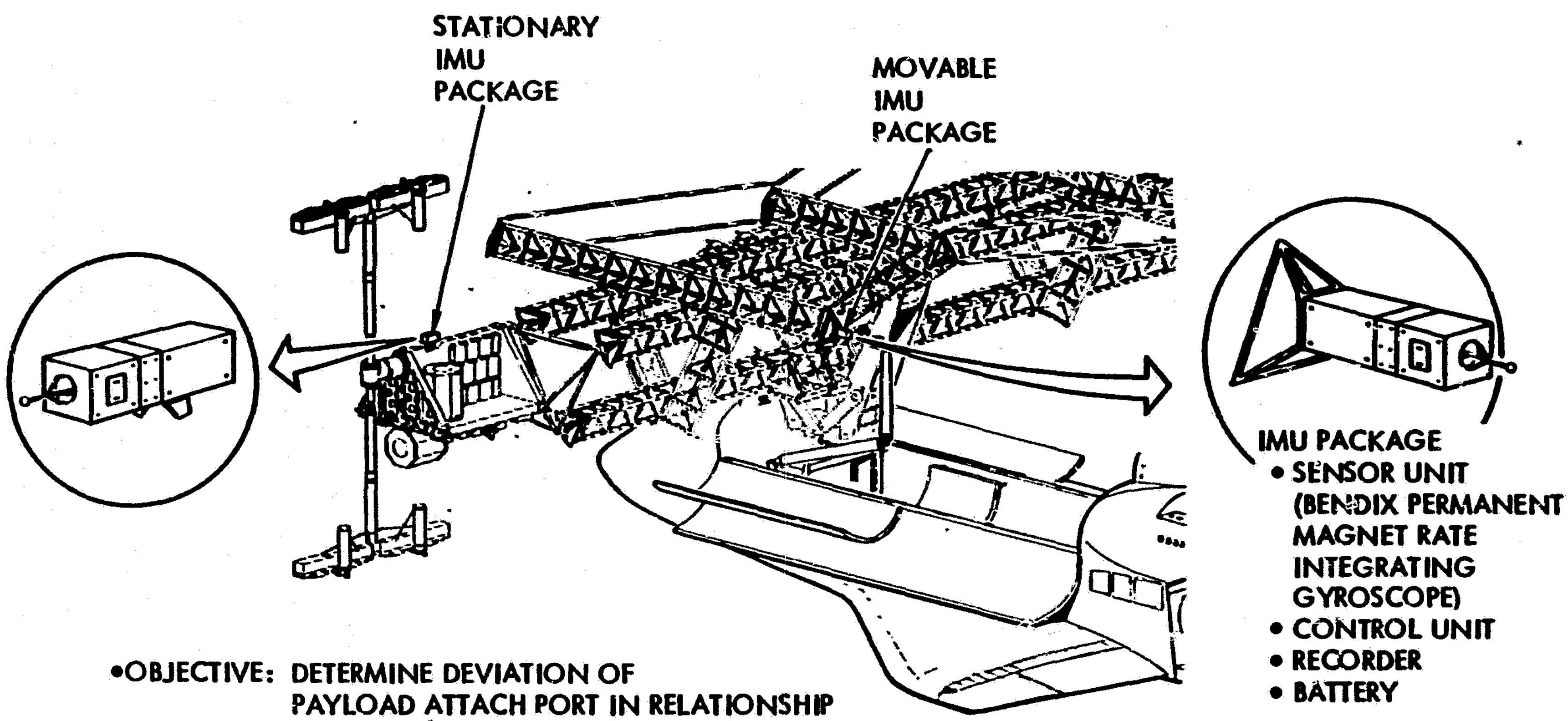
The concept for measuring the misalignment (deviation) between the attitude reference axis (in the SCM) and the attach ports on which RCS and antenna modules would be installed utilizes two special IMU packages.

When the platform is complete - with the exception of the RCS and antenna modules - inertial measuring units (IMU's) will be removed from a precision calibration base within the cargo bay and, using the RMS, deployed into position on the platform.

Two identical IMU's will be used: one will be stationed on the SCM as the reference unit; the other will be attached in sequence to each of the ports - using a female half-port to engage the male half in a manner identical to (for instance) an antenna installation. During the process, both IMU's will record their respective orientations as measured by high precision rate gyro sensors, similar to the Bendix 64 PM RIG sensor used for the International Ultraviolet Explorer Satellite. The IMU's will be completely self-contained (i.e., battery, clock, recorder) so that no connections will be necessary while attached to the platform.

After the final port has been measured, both IMU's are returned to the precision calibration base in the cargo bay for post-measurement calibration. Upon return to earth, the units' recorders would be unsealed, the measurement data reduced, and the alignment biases provided to the various module suppliers.

ATTACH PORT ALIGNMENT CONCEPT



•OBJECTIVE: DETERMINE DEVIATION OF PAYLOAD ATTACH PORT IN RELATIONSHIP TO SCM

•RATIONALE:
- ATTACH PORT DEVIATION AVAILABLE TO PAYLOAD USERS
- PAYLOAD ACCOMMODATES DEVIATIONS
  - ADJUST BEFORE LAUNCH -(.10°)
  - ALIGNMENT TO ACQUIRE GROUND STATION (.25°)
  - AUTO ADJUSTMENT (.025°)

ETVP SERVICING

The platform concept includes provisions for servicing and component replacement at low and high orbits.

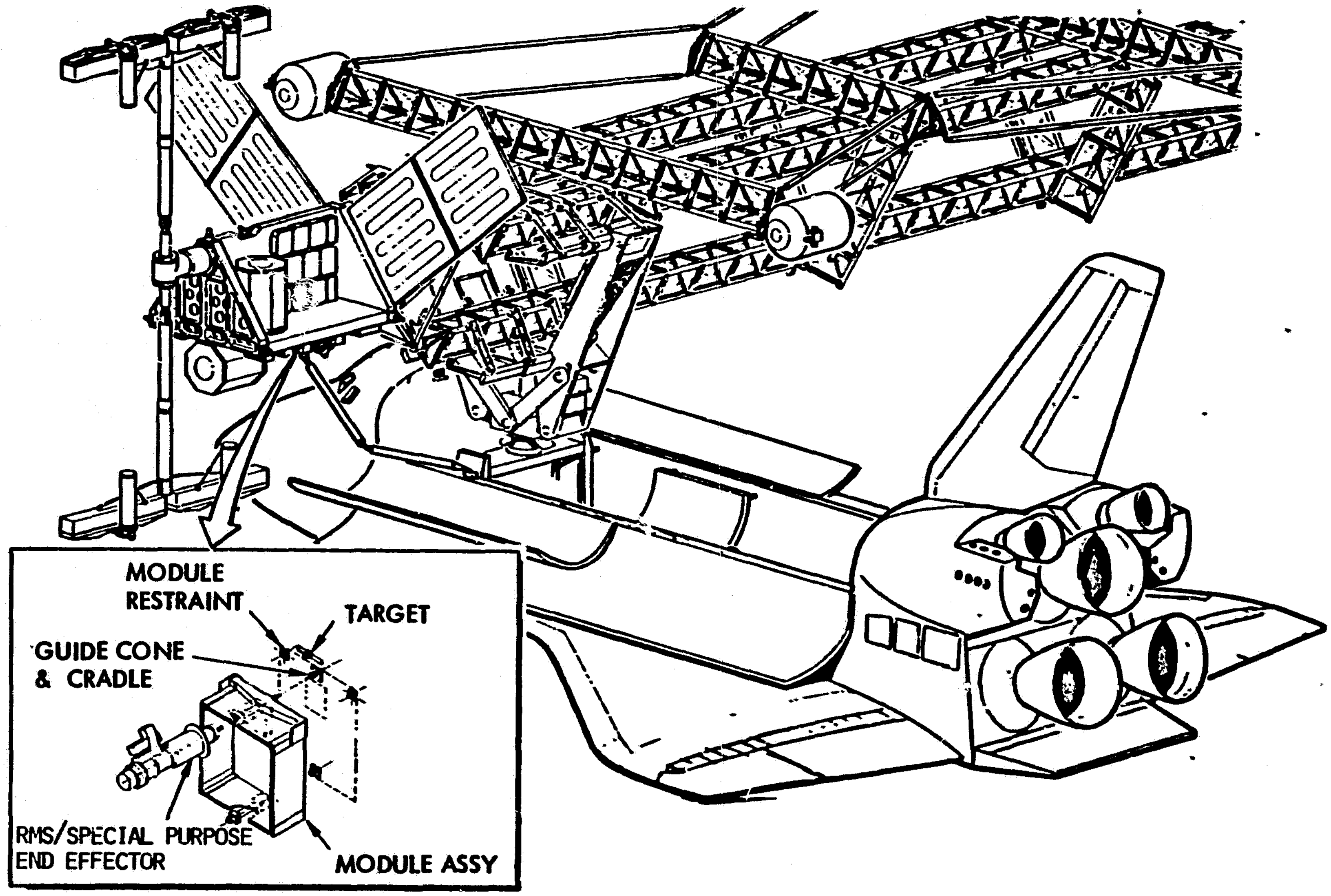
The chart illustrates the potential for accessing the replaceable components in the SCM from the orbiter. As indicated by the inset, the RMS would utilize a special purpose end effector and module installation provisions similar to those proposed for servicing of the NASA/Goddard Multi-Mission Spacecraft.

During the entire low-orbit period of testing, the construction fixture remains attached to the platform - thus providing an interface for orbiter docking and for translation and orientation of the platform for access to all systems.

At the conclusion of the low orbit test phase, the propulsion modules are installed, the fixture is separated from the platform (for return to earth), and the platform is readied for transfer to GEO.

Provisions for GEO servicing are noted by the presence of docking ports on the SCM and near the ends of the long cross-beams where a GEO servicing vehicle may be positioned for access to all replaceable elements.

ETVP SERVICING



The main (Station 1) construction fixture is required to assume several configurations for the construction mission.

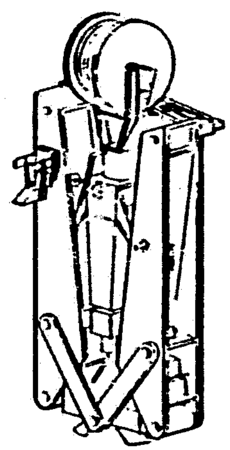
The fixture is brought up in the first launch, and eventually returned to earth, in the folded configuration.

During the initial construction process, the fixture is in the open configuration with the centrally-mounted bridge and EVA work station in place. In addition, this configuration includes, reel mechanisms for deploying electrical lines and structural-stiffening cords. In this configuration, the platform construction is constrained by the bridge to one-way translation only. This limitation is, however, no handicap since the initial construction flows in one direction only - as discussed later.

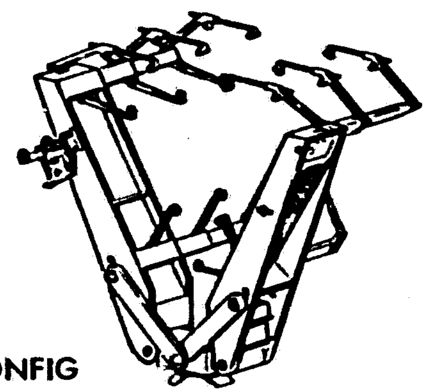
When the platform structure is complete, the no-longer-needed bridge and associated mechanisms are removed from the fixture and returned to earth. In this arrangement the platform is free to translate through the fixture in two directions. This configuration remains with the platform until the low-orbit test phase is completed.

The untended configuration represents the arrangement of the fixture during periods between Shuttle visits and prior to systems activation of the platform. During these untended periods the fixture must provide a minimal level of control (libration rate damping) and telecommunications to enable the returning orbiter to safely berth/dock with the construction system. For these purposes, special panels (lower right-hand diagram) are deployed with solar cells covering alternate surfaces on the opposing panels, and with cold-gas quad jets mounted at the tips. Control analyses have indicated that such a system can limit attitude rates to 0.01 $^{\circ}$/sec. with a nitrogen expenditure of less than 40 lb. per visit. Although the cells are "body-mounted," approximately 70 ft^2 provides sufficient area to maintain battery charge in the gravity-gradient stabilized attitude of the untended system.

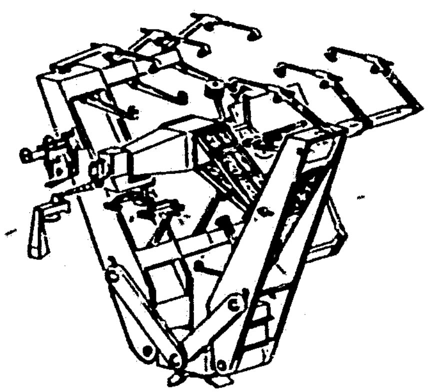
CONSTRUCTION FIXTURE CONCEPT



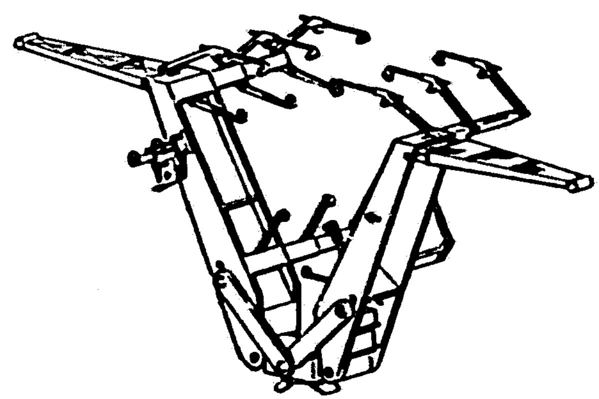
FOLDED
CONFIGURATION



OPENED CONFIG
WITHOUT BRIDGE



OPENED CONFIG.



UNTENDED CONFIG

CONSTRUCTION PROCESS

The following series of charts present the conditions and prccesses required to construct the Engineering/Technology Verification Platform - employing the concepts previously shown.

CONSTRUCTION PROCESS

CONSTRUCTION ORBIT ALTITUDE

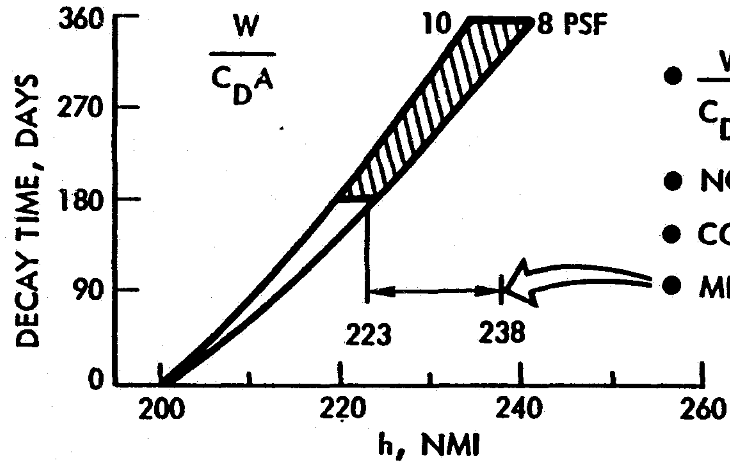
The parameters affecting the selection of the construction orbit altitude consider decay time and orbiter payload weight.

The platform would be built in a 28.5° circular orbit at an attitude of 220-240 n.mi.

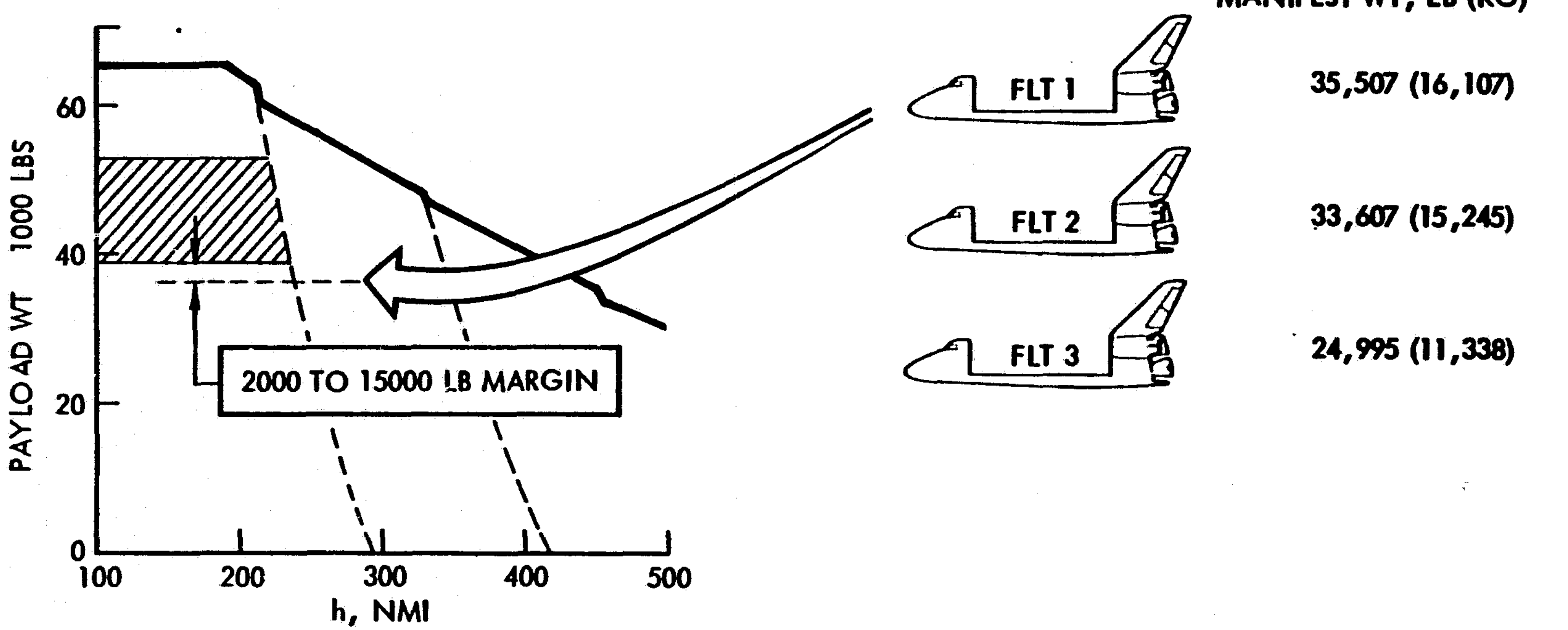
As noted by the upper diagram, this orbit would provide at least several months of contingency time for construction - before requiring re-boost of the assembly to a safer (i.e., non-reentry) altitude.

The lower diagram shows that the standard Shuttle should be capable of delivering the estimated cargos to the construction orbit without requiring an OMS kit in the cargo bay.

CONSTRUCTION ORBIT ALTITUDE



- $\frac{W}{C_D A}$ RANGES FROM 8.3 TO 13.7 PSF, AVG ≈ 10 PSF
- NOMINAL CONSTRUCTION PERIOD, 40 DAYS (2-WK TURNAROUND)
- CONTINGENCY MARGIN ALLOWANCE 6 MO? 1 YR?
- MINIMUM "SAFE" CONSTRUCTION ORBIT ALTITUDE



"FREE DRIFT" CONSTRUCTION ATTITUDE CONTROL

During Part I of the study, we investigated the potential factors which could impose needs for attitude control during the construction process. These factors included orbiter constraints and thermal, loads, communications, illumination, and docking considerations.

From these investigations, we concluded that no requirements were imposed by orbiter operating limits; nor by thermal, lighting/visibility or communications constraints. Proceeding, then, with the overall design philosophy, that no hardware (i.e., flight control in this instance) be added to the system without a clear demonstration of need, we investigated the implications of a "free-drift" attitude approach. In this approach, the principal issues of concern were the inertial loads (centrifugal and coriolis) due to angular rates and orbiter revisit/docking.

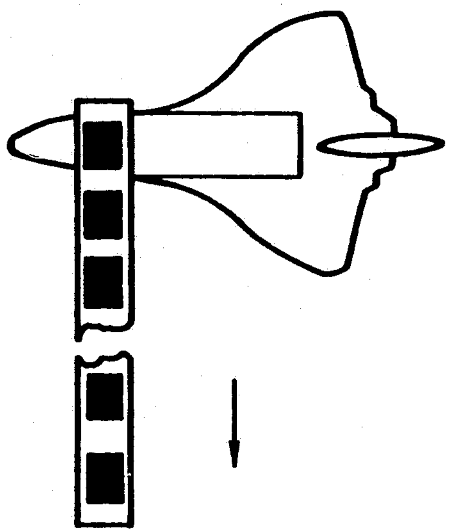
The investigation of loads due to the controlled angular rates was performed using Rockwell's VARMAP (Variable Mass Properties) 6-DOF rigid body program. With this program, we were able to analyze the inertial rates of the orbiter-construction system during the simulated construction process shown in the left-hand diagram.

As noted in the right-hand diagram, the resulting rates were generally less than 0.1 ^{o}/sec and the resulting loads were inconsequential. Other similar runs, treated with conservative initial conditions, indicated similar results.

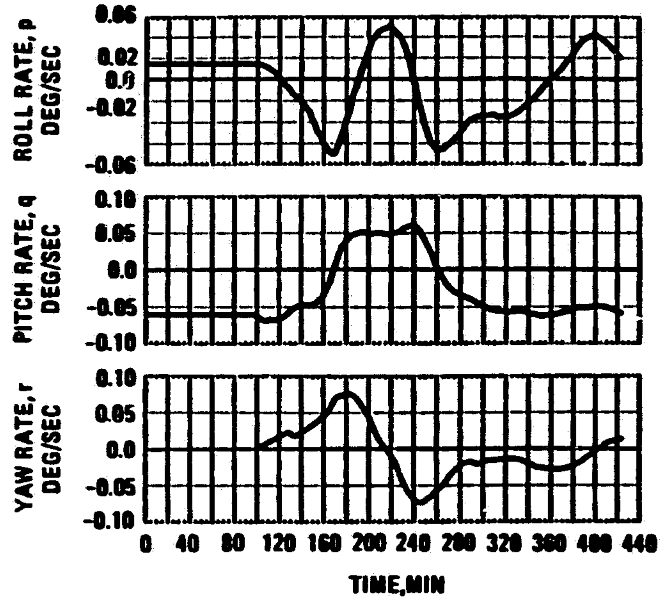
With respect to revisit/docking, as earlier noted (see Page 24), a libration damper was integrated into the construction fixture to limit the angular rates to those within the capacity of the orbiter's RMS to match and to dissipate the differential energy between the masses.

"FREE DRIFT" CONSTRUCTION ATTITUDE CONTROL

PART I ANALYSIS



BODY RATE HISTORY



- TRANSLATE 36,000 KG MASS
  5 STEPS
  1 METER/MIN
- AFTER EA TRANSLATION STEP
  MOVE A 4,500 KG MASS
  FROM BAY TO PLATFORM
  ≈3 METER/MIN

RESULTS

- NO "TUMBLE"
- LIBRATING MOTION < 0.1 °/SEC
- NO SIGNIFICANT CONSTRUCTION IMPACTS
- MINIMAL LIGHTING INTERFERENCE
- ORBITER HEAT REJECTION SATISFACTORY

CONSTRUCTION SEQUENCE

The following six illustrations show the general sequence used for constructing the platform.

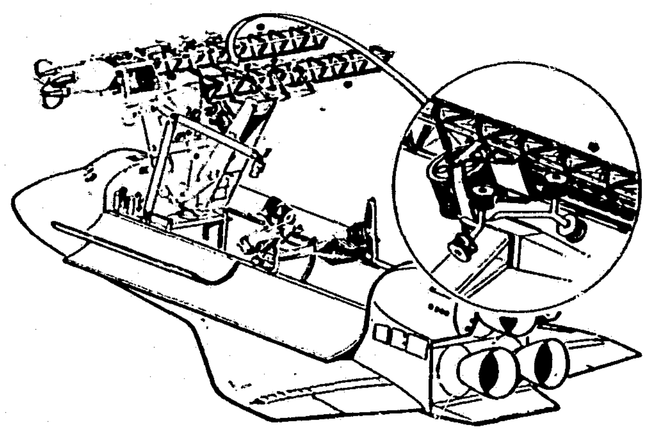
The initial activity is organized to set up the main construction fixture and to fabricate the three longitudinal beams in sequence. The main power and data distribution bus/harness is installed on the inside face of the first-made beam.

With the longitudinal structure in place, the beam-builder is moved to the secondary work station where the transverse beams are fabricated. At this station, payload attach ports and electrical harnesses are installed on the payload-carrying beams. As each transverse beam is completed, it is transported by the RMS to the main fixture for joining to the longitudinal structure. The operations of joining the beams (structurally and electrically) are facilitated by the EVA crewman stationed aboard the main fixture (see Page 15).

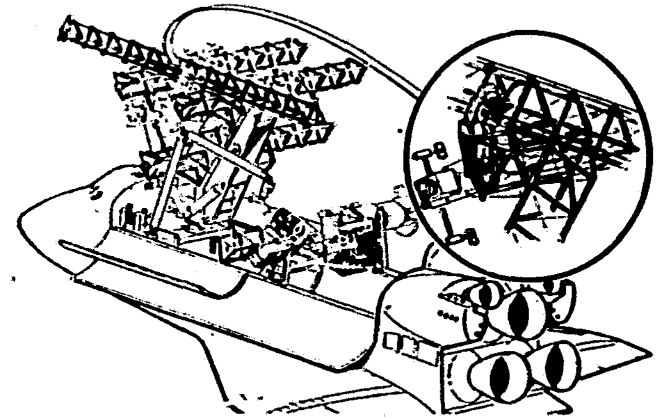
As each set of transverse beams (three per longitudinal station) are installed, the structural assembly is translated through the fixture, thereby drawing out the diagonal tension cords from fixture-mounted reels. At the next longitudinal station, the cords are attached to the next set of transverse beams and tensioned by the astronaut to a pre-planned schedule of forces.

This cycle of activities is repeated until the entire tri-beam structure is complete.

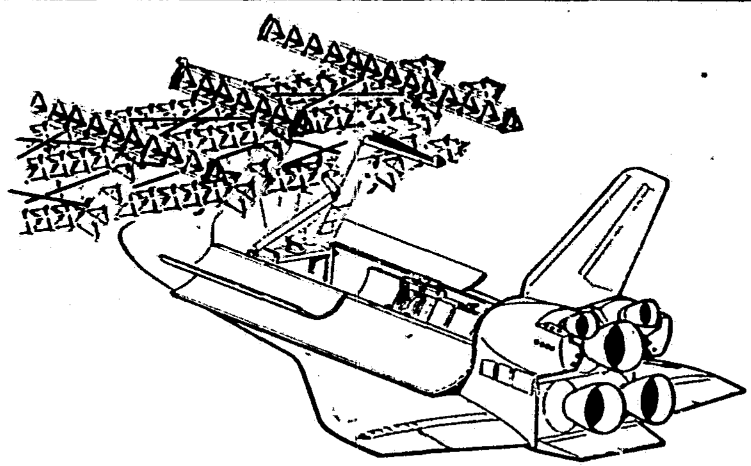
CONSTRUCTION SEQUENCE



- FABRICATE LONGITUDINAL BEAMS
- INSTALL WIRE HARNESS



- FABRICATE TRANSVERSE BEAMS
- ASSEMBLE TRANSVERSE BEAMS TO LONGITUDINAL BEAMS
- MAKE ELECTRICAL CONNECTION



- INSTALL & TENSION DIAGONAL CORDS

CONSTRUCTION SEQUENCE (Continued)

With the structure complete, the fixture is reconfigured (removal of the central bridge and EVA work station) so that the structure may be translated in both directions to accommodate the following operations.

At the forward section of the platform, the support structure for the control module is deployed and attached to the ends of the longitudinal beams. The control module is then attached at three points and its electrical systems connected across to the main distribution bus/harness.

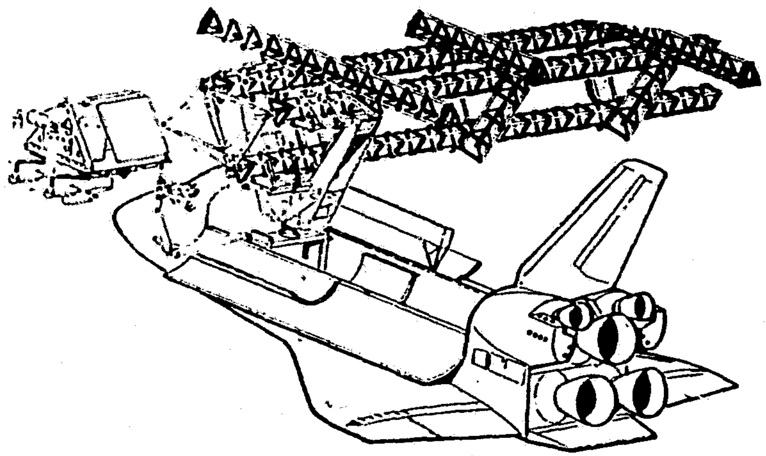
As the platform is translated toward the aft end, bracing struts are installed to support the long cross beams against the thrust loads during orbit transfer.

At the aft end of the platform, a deployable thrust structure is installed in a manner similar to that of the control module support structure.

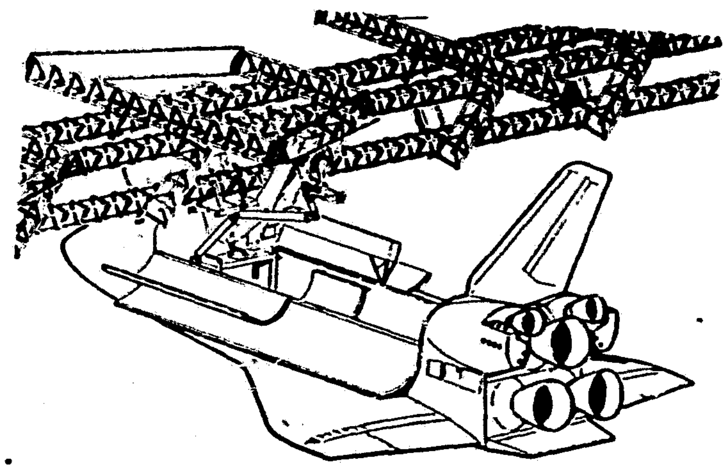
The final step in the construction of the platform is the installation of the four RCS modules at the extreme forward and aft cross beams, and the installation of payload modules (e.g., antennas) at attach ports on the intervening cross beams.

Structural and functional checks of the platform are conducted during and at the conclusion of the construction process. The first coarse structural check is made by optical sightings from the EVA work station as each structural bay is completed. Precision measurements are made by inertial instrumentation (see Page 21) when the structure is complete. Functional checks are made after the control module is installed and at the completion of construction.

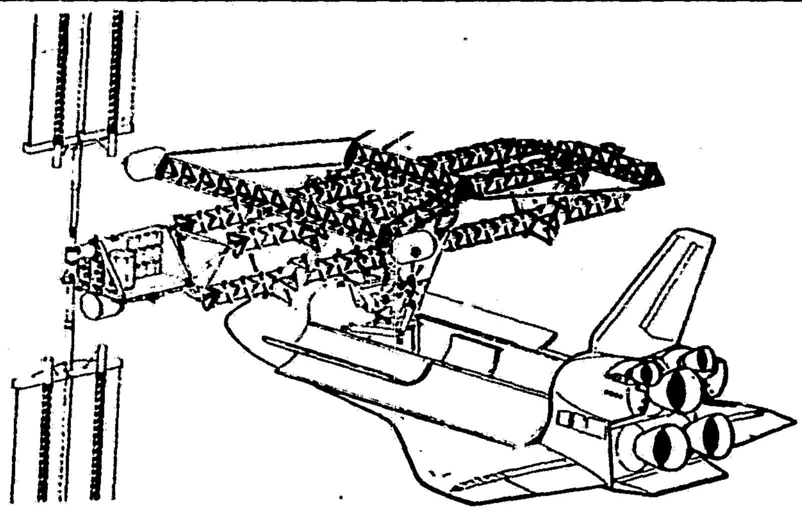
CONSTRUCTION SEQUENCE



- INSTALL SYSTEMS CONTROL MODULE SUPPORT STRUCTURE
- INSTALL SYSTEMS CONTROL MODULE



- INSTALL CROSSBEAM BRACING STRUTS



- INSTALL RCS MODULES

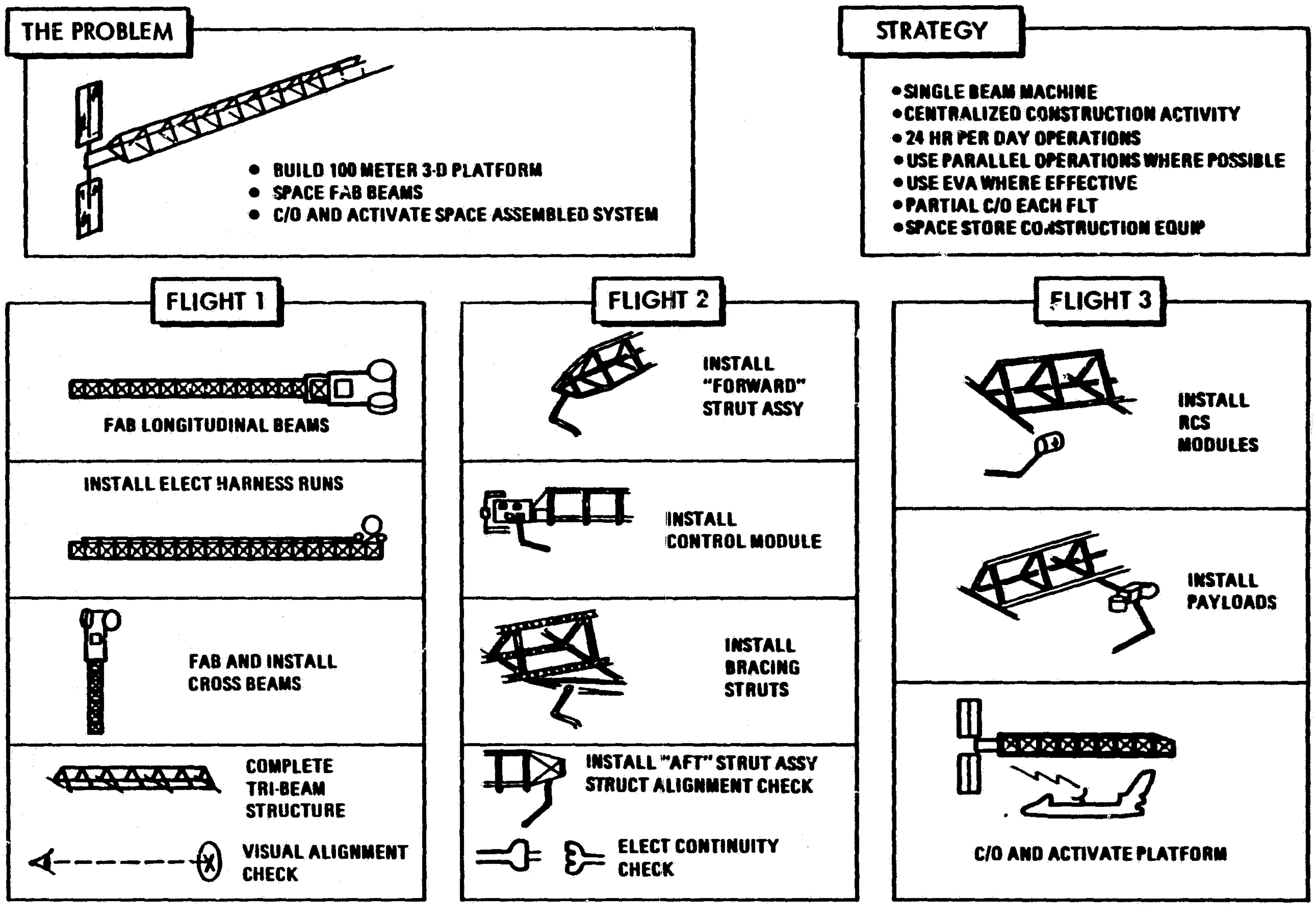
CONSTRUCTION SCENARIO AND RATIONALE

A summary of the construction process just described shows the division of the construction operations between the three flights needed to complete the platform.

It is noted that a single beam machine of the type designed by General Dynamics has been assumed for this analysis. Although multiple beam machines might have facilitated the construction operations, the additional orbiter cargo bay space and power required would have been a serious penalty.

It is further noted that construction operations were scheduled around-the-clock. Our studies have indicated the need to complete the construction operations in the shortest practicable time for the following reasons: (1) beyond approximately nine days, the power drain of orbiter housekeeping adds to that of the construction operations - leading to increased fuel cell cryo kit requirements; (2) the charging policy for Shuttle operations amounts to over 1/3 million dollars per 24 hour day; (3) time allowances should be made for unforseen contingencies. Although around-the-clock operations impose greater demands on the crew, our analyses - as noted later - indicate that a six man crew can reasonably be expected to perform the required operations on a three-shift basis.

CONSTRUCTION SCENARIO AND RATIONALE



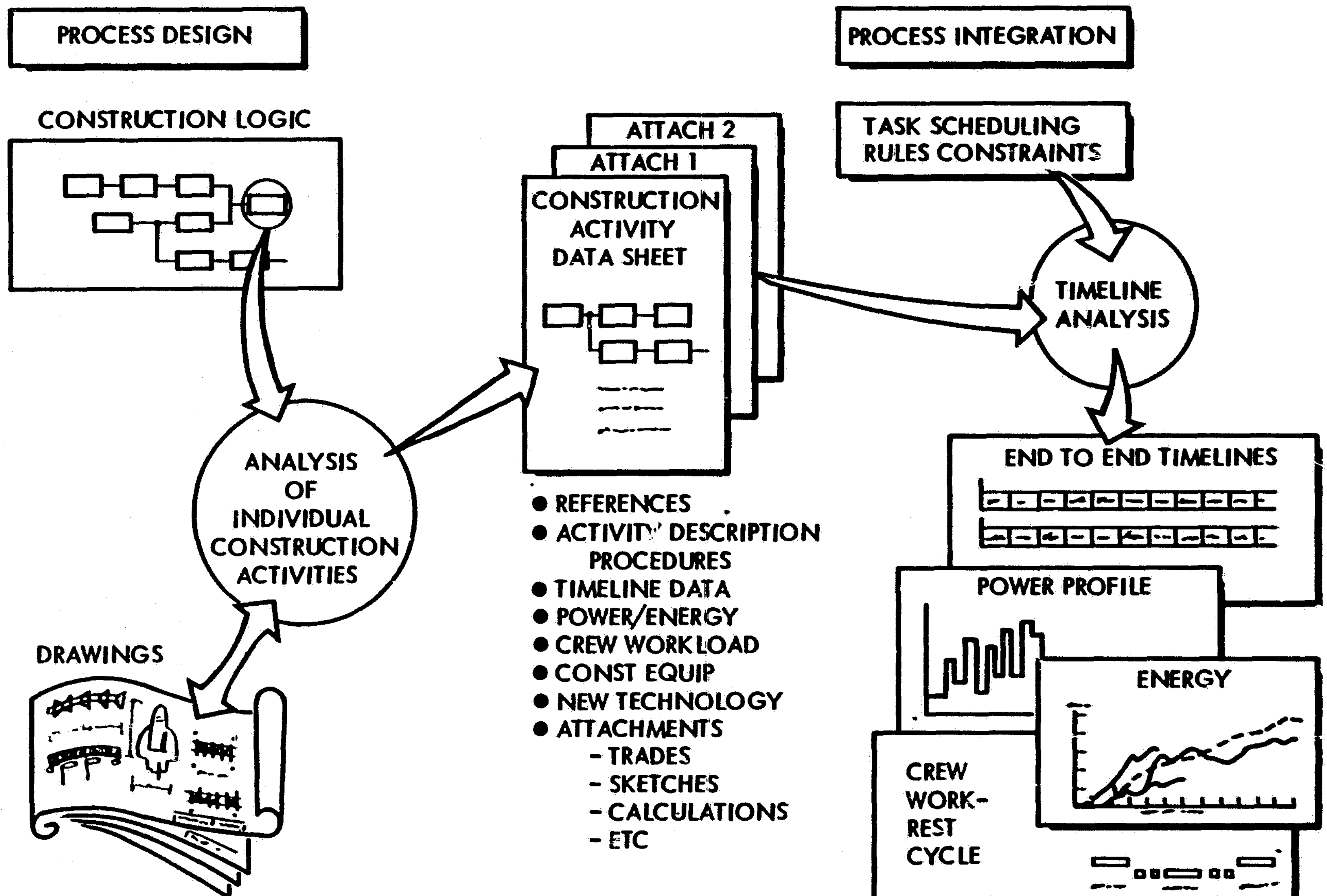
OPERATIONS ANALYSIS TECHNIQUES

The construction analysis began with the preparation of an end-to-end logic which identified all activities required to construct the platform. The logic provided a framework for the identification of all initial conditions prerequisite to any given activity, as well as for the recording of parallel activities which could be of consequence. As was expected, the logic evolved through a series of iterations; i.e., downstream activity analyses showed needs to revise the construction plan.

Each of the activities in the logic was analyzed as an entity and documented in the form of drawings and activity data packages. In the course of this study, 43 such packages were prepared.

The techniques of process integration was concerned with the melding of the construction activities into flight-by-flight construction missions. This was accomplished by considering the limitations of cargo bay packaging, flight duration, power and energy supply, and crew manning and duty cycles. The following text presents some of the significant considerations which influenced the results of this analyses.

OPERATIONS ANALYSIS TECHNIQUES



No text required.

GROUND RULES AND ASSUMPTIONS

- START CONSTRUCTION WHEN ORBITER READY AT CONST ORBIT
- CONSTRUCTION SHUTDOWN PRIOR TO ORBITER SEPARATION
- CREW WORKSHIFTS CAN BE MATCHED TO CONST OPS
- SINGLE EVA PERMITTED (IVA READY FOR RESCUE)
- SCHEDULE EVA BACK-TO-BACK FOR MULTISHIFT OPS
- IVA &/OR "OFF DUTY" CREW PERFORMS ROUTINE ORBITER HOUSEKEEPING OPS
- IVA CREW CROSS TRAINED ALL IVA TASKS
  EVA CREW CROSS TRAINED ALL EVA TASKS
- EVA CREW GIVEN 10 MIN REST PER HOUR PLUS 20 MIN REFRESHMENT PER SHIFT
- PARALLEL OPS SCHEDULED WHERE CREW/DUTY STATIONS/POWER CONSTRAINTS PERMIT
- MAX CONSTRUCTION POWER AVAILABLE IS 7 KW (12 KW PEAK)
- CONSTRUCTION EQUIPMENT OPERATIONS
  - BEAM MACHINE FAB RATE : 1.08 M PER MINUTE
  - MAIN FIXTURE TRANSLATION RATE : 2.16 M PER MINUTE
  - RMS TRANSPORT RATE : 4 TO 40 M PER MINUTE
  - EVA STATION TRANSLATION RATE : 3 M PER MINUTE

CREW MANNING LEVEL/EVA

One of the more significant conclusions of the present study is the need to develop a higher pressure suit for EVA construction operations.

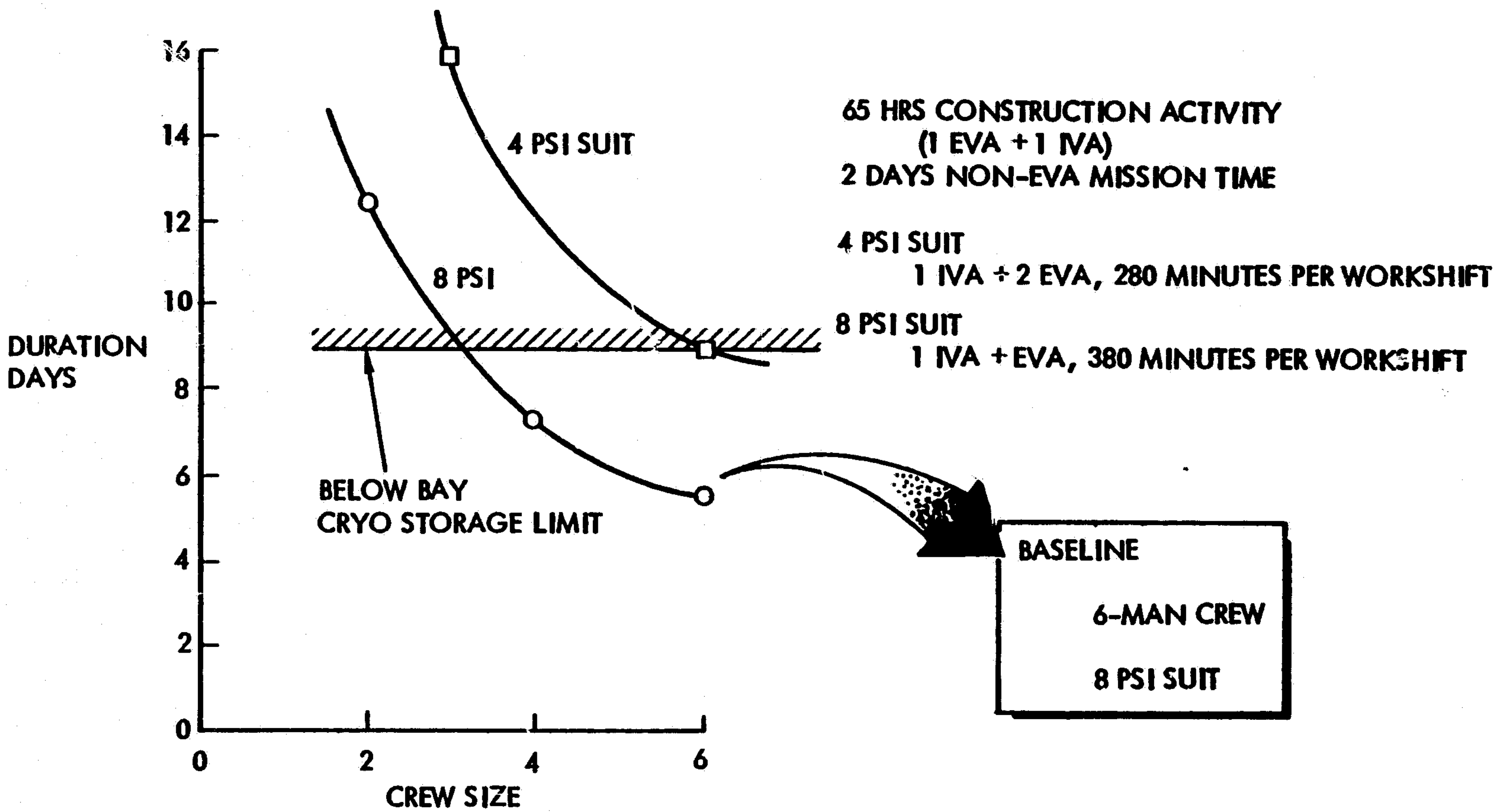
This chart presents an evaluation of the presently baselined 4 psi suit in comparison with an advanced-technology 8 psi suit. In this evaluation, we assumed a 65 hour construction time requiring one IVA and one EVA crewman on each of the three shifts. The IVA crewman controlled the construction operations, the RMS, and orbiter housekeeping from the payload specialist station on the aft deck. The EVA crewman performed all cargo bay operations - either from the fixture-mounted EVA work station or from the open cherry picker at the end of the RMS arm.

With the 4 psi suit, the EVA crewman is required to spend three hours pre-breathing in preparation for EVA activity. Because of the pre-breathing requirement, and because rescue of the EVA crewman must be available at all times, the effective work product of the crew would be adversely impacted - either by the need to have the IVA crewman on pre-breathing for his total shift (limited to six hours on 14.7 psia O_2) or (preferably) by having a buddy EVA crewman in the bay. In the latter case, productive work would be limited to 280 minutes per three-man workshift.

However, with the 8 psi suit, no pre-breathing would be required and the suited IVA crewman could perform a required rescue with minimum delay. Thus, a two-man work crew (one IVA and one EVA) could accomplish more work per shift since the shift time could be extended to eight hours.

The result, then, of the 8 psi suit is greater productivity per crewman - leading to smaller crew sizes and/or shorter missions. In the interest of accomplishing the missions in the shortest practicable time - and allowing margin for unknowns - we have elected to baseline the construction missions around a six-man crew, each of which is equipped with an 8 psi EVA suit.

CREW MANNING LEVEL/EVA



MISSION 1 CARGO MANIFEST

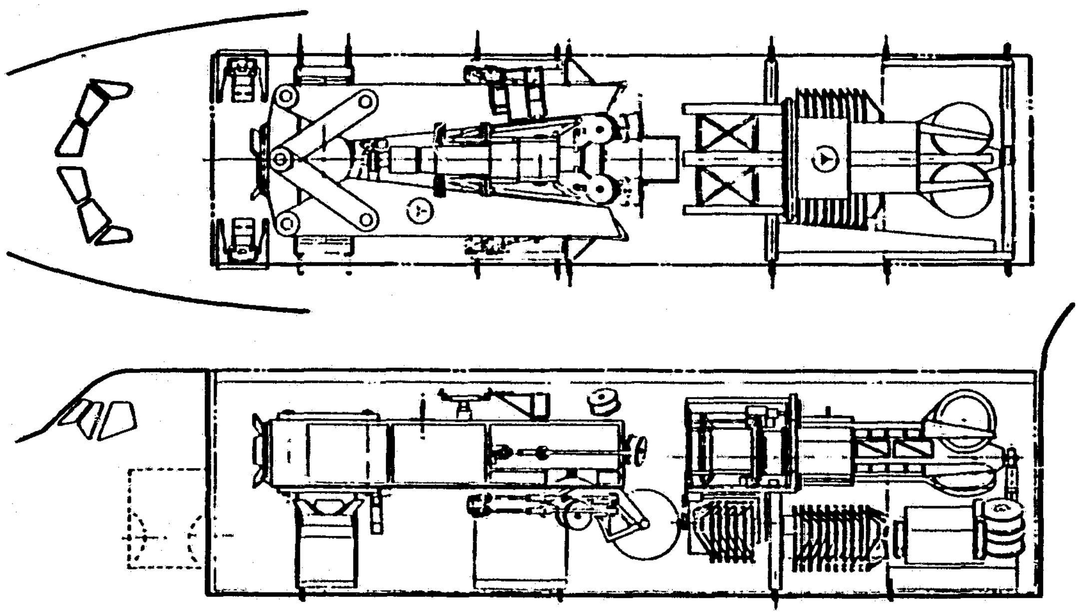
An illustration of the cargo bay packaging for the first flight mission is shown; a detail drawing of the installation has been included in the engineering documentation.

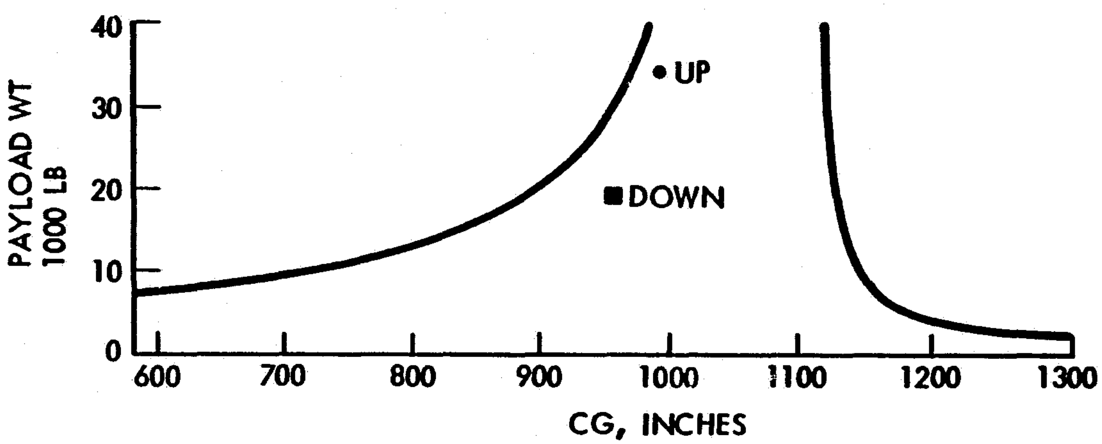
It is noted that the main construction fixture, beam machine, payload attach ports, and electrical harness reels dominate the cargo bay envelope.

Arrangement of the cargo items has been designed to accommodate item deployment and use without disturbance to the remaining items. It may also be noted that the large items (e.g., construction fixture) are supported by integral trunnions attached directly to the sill bridge fittings/latches and to the keel fittings. The orbiter/fixture docking port is shown retracted, directly beneath the forward section of the main fixture.

It is interesting to note that the payload-chargeable weight divides almost equally in three parts: platform flight hardware, construction support equipment, and mission-peculiar orbiter provisions. As shown, payload weight and balance is within the orbiter's allowable envelope.

MISSION 1 CARGO MANIFEST





WEIGHT, LBS

PLATFORM MATL'S	
BEAM STOCK	2,761
CORD ASSY	75
ELECT	1,996
INTERSECT FITTINGS	198
ATTACH PORTS	6,468
	11,498
CONSTRUCTION SYST	
MAIN FIXTURE	5,814
BEAM MACHINE	5,738
AUX MECHANISMS	500
ORBITER I/F EQUIP.	440
RMS END EFFECTOR	100
	12,592
ORBITER PROVISIONS	
CRYO AND N_2	2,068
CRADLES, FITTINGS, ETC	7,618
EXTRA CREW AND EQUIP.	1,731
	11,417

Σ = 35,507 LB

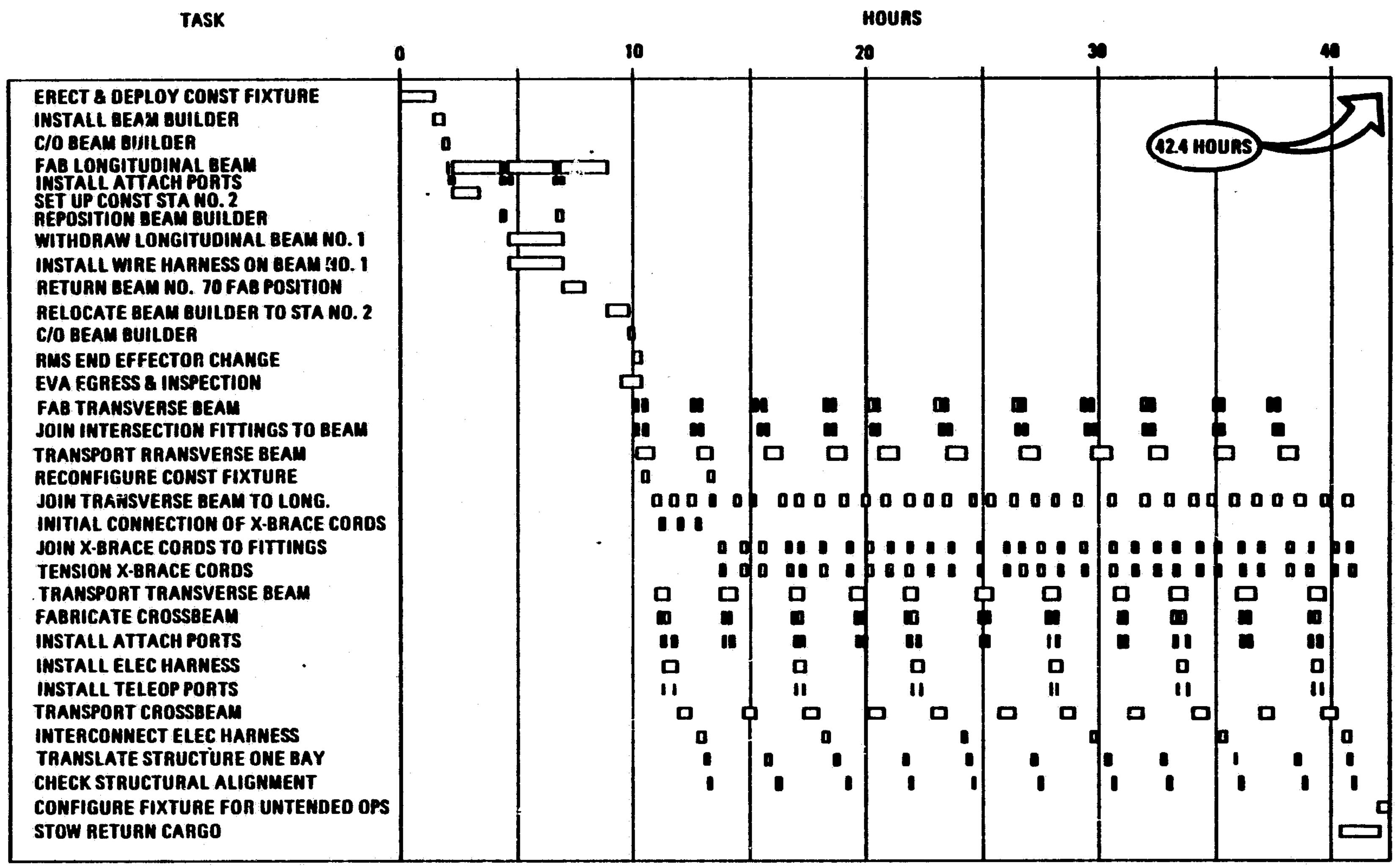
CONSTRUCTION TIMELINE

A summary timeline for construction operations during the first flight mission is shown. This timeline is the synthesis of detailed analyses which typically consider individual events of one minute (and less) duration.

The timelines were generated in a series of iterative steps. In the first step, the activity times were laid end-to-end according to the construction logic. The second step accounted for the crew work assignments, EVA suit donning and doffing, and duty-rest cycles. The third step integrated the time sequences between parallel interactive operations; e.g., the "parking" of the RMS in the intervals between its transport operations in a position to take advantage of its lights and viewing cameras while performing other parallel operations. The fourth step, which actually overlapped the preceeding steps, considered the power-peaking problem and the need to "slip" operations to avoid unreasonable exceedances.

In general, the time estimates were based upon available data from Apollo and Skylab flight experience and simulations in JSC's MDF and MSFC's NBS facilities. Furthermore, the time estimating policy was to err on the long side - to the best of our knowledge. To account for "I forgots" and uncertainties, a 50% time factor was added to the estimated value; this is discussed in later charts.

CONSTRUCTION TIMELINE



REMOTE VIEWING AND LIGHTING AIDS

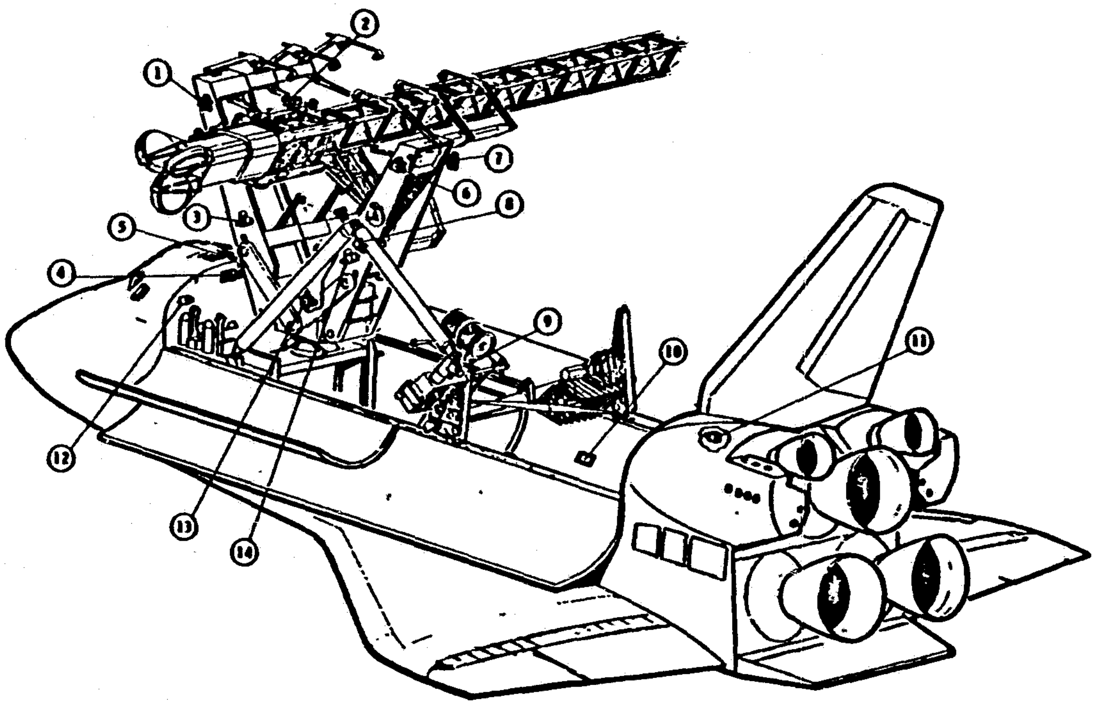
Various lamps and TV cameras are required for seeing and controlling the construction operations from the IVA and EVA work stations. Details supporting this chart are available in the engineering documentation.

The requirements call for 17 lamps, including the 8 baselined as standard on the orbiter/RMS and 11 TV cameras, including the 4 baselined for orbiter/RMS.

The general policy regarding visibility/illumination has been to locate the EVA crewman in positions to visually monitor all clearance-critical operations (e.g., transporting a transverse beam from the secondary work station to the primary fixture), and to provide an industrial standard of lighting within the immediate proximity of the detail work (e.g., positioning the transverse beam for joining to the longitudinals).

Estimated power requirements for lighting is 2 kW peak and 1 kW average - assuming selective use of the lamps for the various construction operations.

REMOTE VIEWING AND LIGHTING AIDS



No.	Light(s)	TV Camera
1	√	√
2	√	√
3	√	√
4	√	
5	√	
6	√	√
7	√	√
8		√
9	√	√
10	√	
11		√
12		√
13	√	√
14	√	√

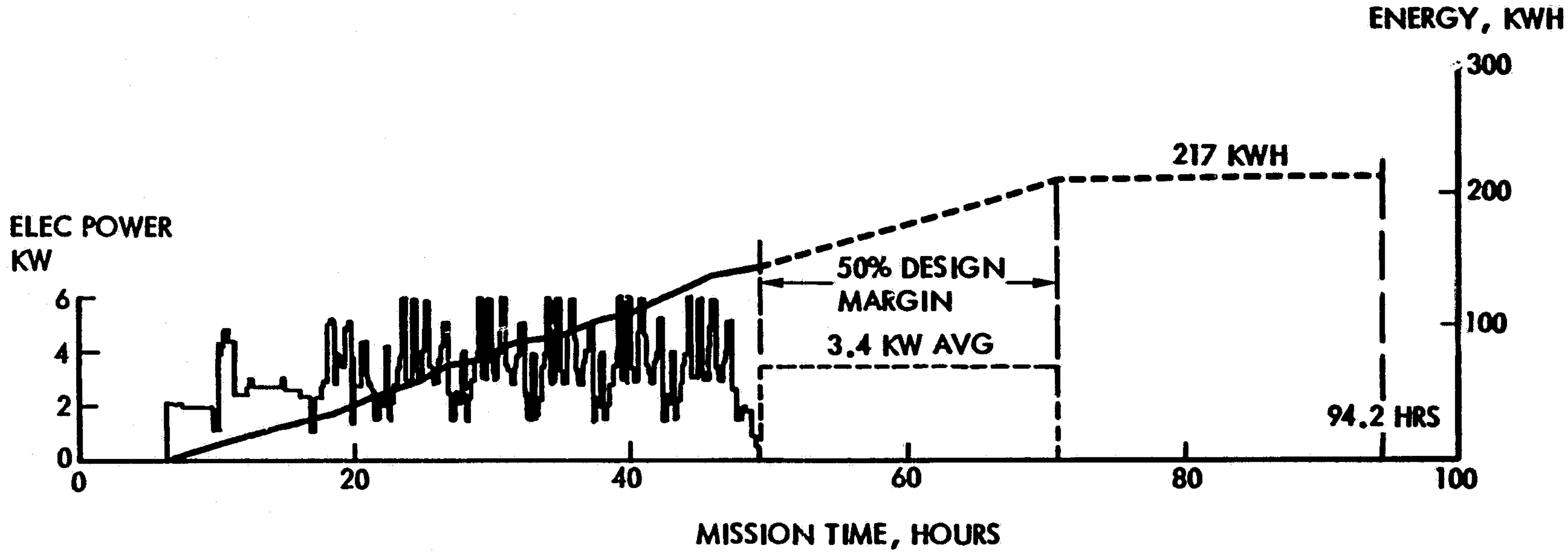
ELECTRICAL POWER/ENERGY - MISSION 1

The power and energy profiles associated with construction are over and above those associated with basic Shuttle ascent, orbit, and descent operations and are, therefore, payload-chargeable requirements.

It is noted that lighting requirements account for approximately one-third of the peak and average power levels - the beam machine and RMS account for most of the balance. The peak power levels are generally within the 7 kW maximum continuous power allocated to the orbiter's payload.

As earlier noted, we have included a 50% design margin for potential under-estimates of the construction timelines. This time margin has been incorporated into the energy requirements by assuming a straight-line extrapolation of the average construction power consumption. On this basis, the payload-chargeable energy requirement is seen to exceed the 50 kWh which the basic orbiter can make available to its payload. Therefore, the first mission will require the addition of a cyro tank ket (below the cargo bay liner) to accommodate the needed energy.

ELECTRICAL POWER/ENERGY - MISSION 1



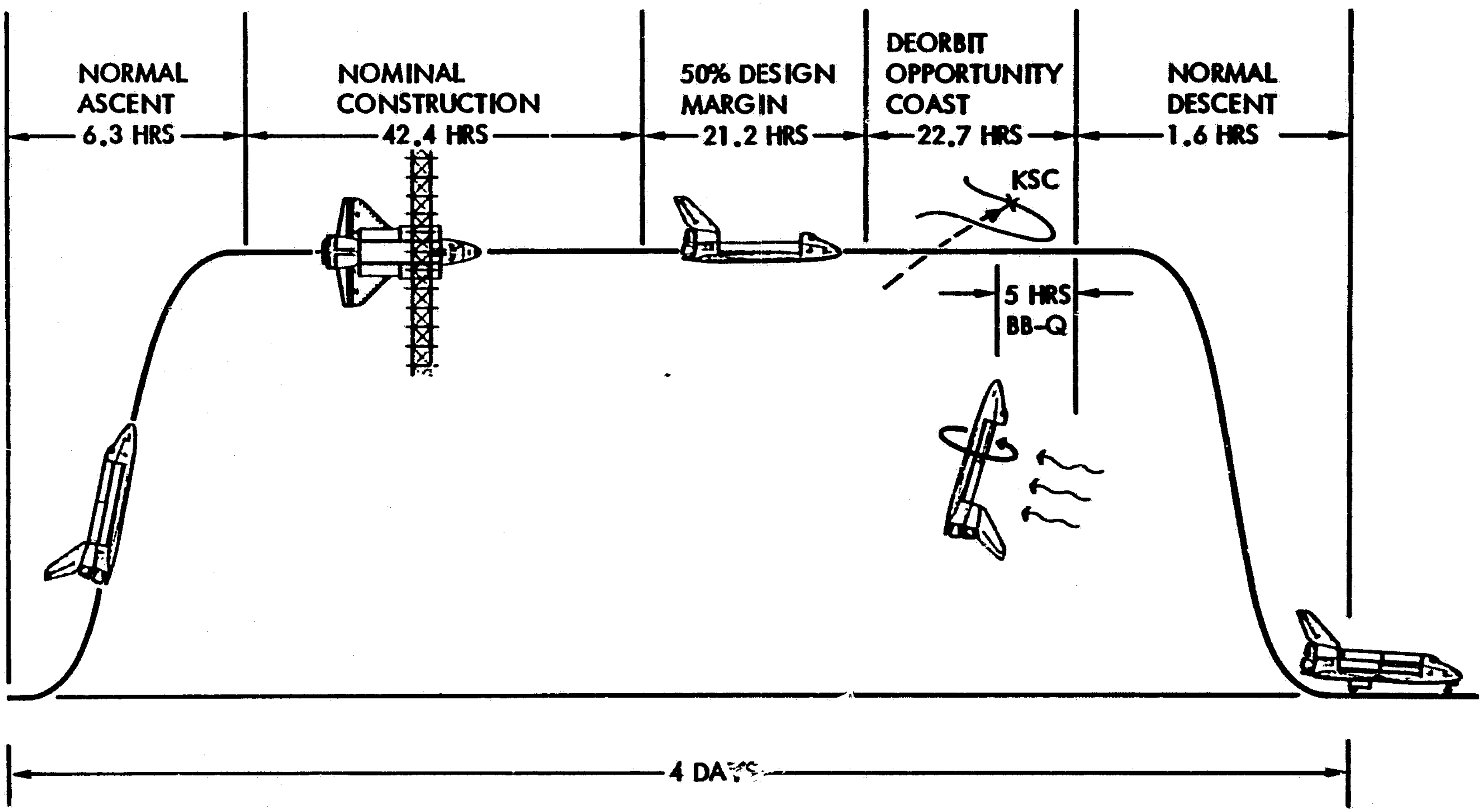
FLIGHT NO. 1 PROFILE

The flight profile for the first construction mission assumes that the initial construction activity (i.e., setting up the main construction fixture) can commence immediately following the securing of the orbiter for construction operations. The pre-launch conditioning of the crew and the subsequent crew duty-rest cycles have accounted for this assumption.

At the conclusion of the construction operations, the orbiter separates from the construction fixture and prepares for its reentry and descent to KSC. Time allowances have been made for the orbit path to project over KSC, including an allowance for checkout and thermal conditioning for the reentry phase.

This first mission builds the platform structure and its power/data distribution system. At completion, the orbiter returns to base with the no-longer-needed beam machine and main fixture center bridge. The profiles for the second and third missions are discussed in the following pages.

FLIGHT NO. 1 PROFILE



FLIGHT NO. 2 PROFILE

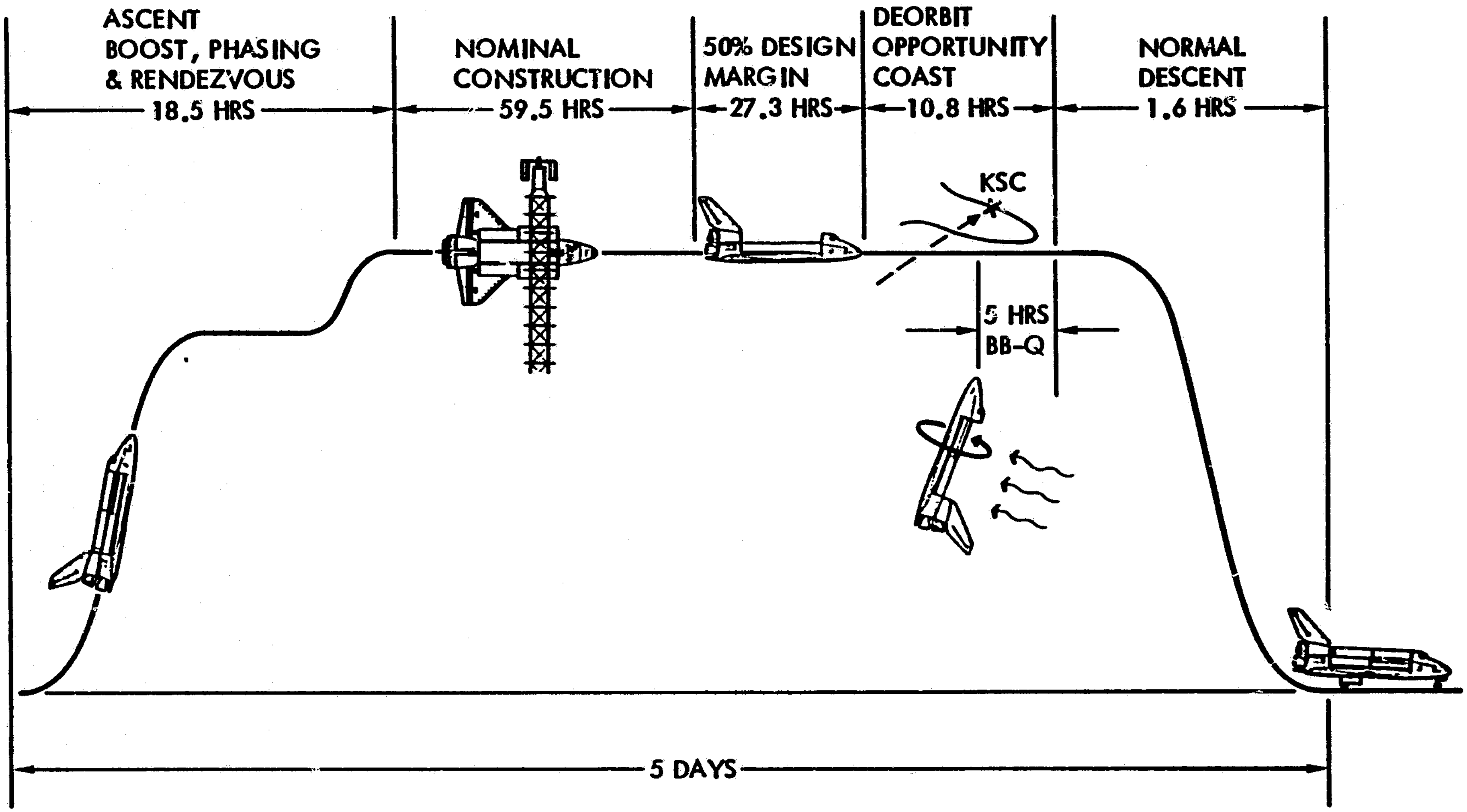
The requirement for rendezvous and berthing with the orbiting construction system extends the ascent phase to nearly one full day.

Prior to launch, command signals would be transmitted to activate the fixture's libration damping system and its rendezvous aids to provide a stable cooperative target for revisit.

Construction operations in this mission include the installation and checkout of the platform's control module (including its solar array), checkout of data/power distribution, installation of the aft thrust structure, cross beam bracing struts, and precision measurement of the structural alignment of the platform. Most of these operations involve an EVA crewman stationed aboard the open cherry picker at the tip of the RMS.

The duration of the mission is paced by the serial times required to checkout the control module, the distribution system, and to perform the structural alignment measurements.

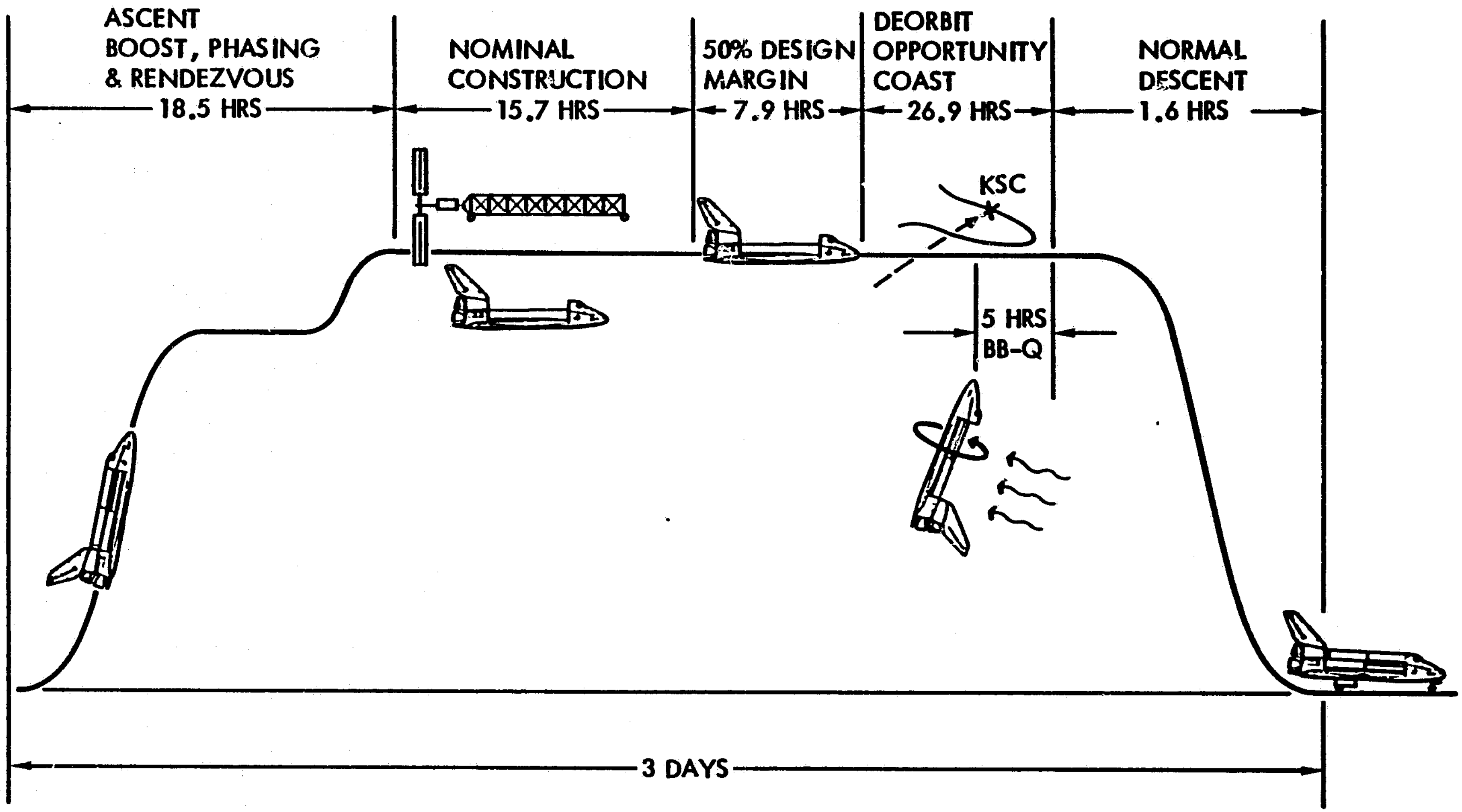
FLIGHT NO. 2 PROFILE



FLIGHT NO. 3 PROFILE

This mission profile is contracted to that required to install the four RCS modules and to activate/checkout the platform for low-orbit operations. As a practical matter, this mission would include the installation of such test payloads as may be appropriate to the ETVP objectives. Our layouts for the bay packaging and estimates of mass properties for the third mission indicate that approximately 16,000 lbs. of lifting capacity and two-thirds of the bay would be available for payload over and above the RCS modules.

FLIGHT NO. 3 PROFILE



SUMMARY - SHUTTLE PROVISIONS & MODIFICATIONS FOR SPACE CONSTRUCTION

Identified here are the most significant requirements that are imposed on the orbiter for support of space construction.

The aft deck console area must be configured for the control of the construction fixtures at Stations 1 and 2 and for the operation of the lights and CCTV cameras and payload latches. Software for the construction management and for collison-avoidance is also required.

Accommodation of the six-man crew will require additional seats and restraints and stowage provisions and appropriate rescue equipment. Special rest/sleep provisions to reduce noise and light may be required to support the multi-shift operations.

The three-shift operations will require four additional EVA suits and supporting accommodations. Stowage of the additional suits can be accommodated in the payload bay by utilizing a thermally controlled container. Plumbing and valve changes may be required for servicing of the 8 psi suit pressure.

Additional supplies of N_2 are needed to support the EVA airlock operations. Plumbing modifications are required in the orbiter to accept the additional two tanks of high pressure nitrogen.

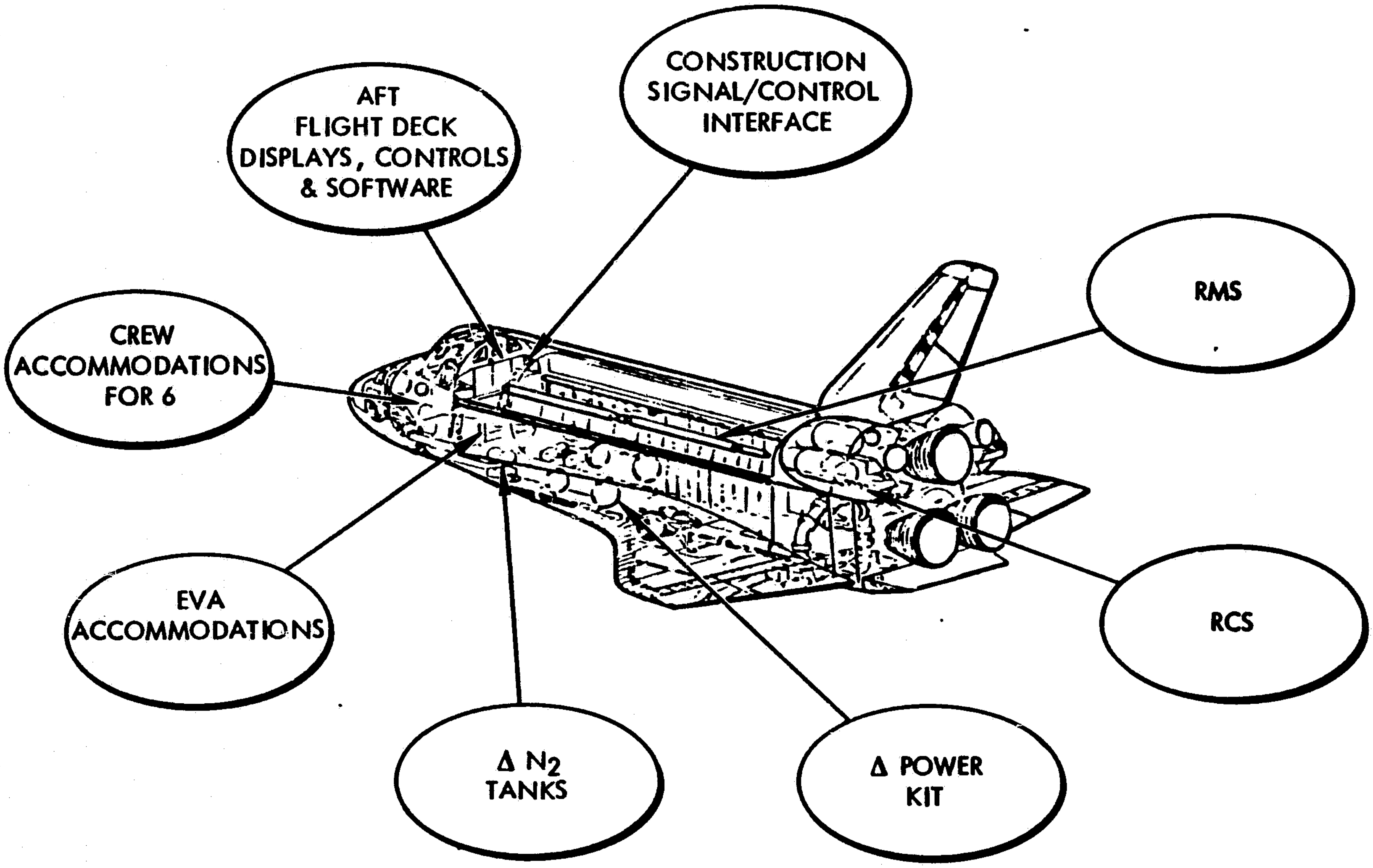
One additional cryo kit is required to provide the electrical power for construction; provisions are available under the payload bay liner to accept this installation.

The revisit/berthing maneuver will require precision RCS control of translation and attitude in order to effect RMS engagement for berthing. Flight control requirements associated with the berthing and construction operations will impact control system software and jet-select logic.

An RMS upper arm rotary joint is required to perform the construction operations identified in this study. A pan and tilt capability of the wrist mounted TV camera and light is also highly desirable.

An interface connection for the control/management of the construction fixtures, lights, and latches is required to complete the circuit to the aft flight deck construction controls and displays. This provision is available via payload dedicated penetrations in the crew module aft bulkhead.

SUMMARY - SHUTTLE PROVISIONS AND MODIFICATIONS FOR SPACE CONSTRUCTION



CONSTRUCTION SUMMARY

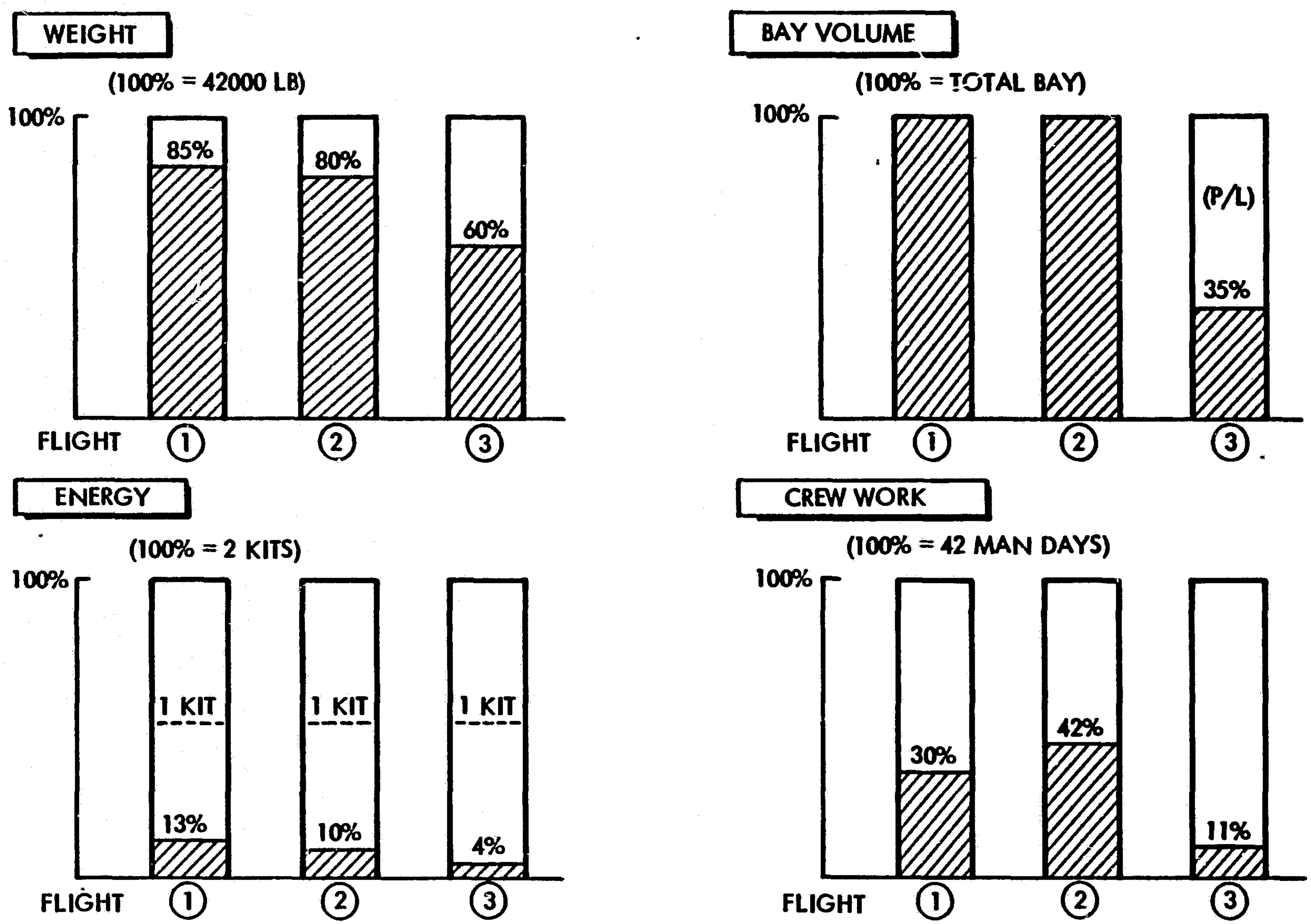
The number of missions to construct the basic platform was driven by cargo bay packaging limitations. As previously noted, the third mission would also be expected to be filled to capacity with initial test payloads and experiments which are yet to be defined.

Although packaging was the driver, weight was not far behind and, in fact, is in good proportion to the bay volume and lifting capacity of the Shuttle without OMS.

The energy picture shows a substantial (and surprising to our earlier estimates) margin of capacity relative to the energy available from two fuel cell cryo kits stored below the cargo bay liner. This margin suggests that, even with increased consumption, one kit may be sufficient.

The crew work load is shown to be moderate when compared to the orbiter's basic accommodations of up to six men for up to seven days. This margin is, however, deceptive because the six-man crews are employed for typically less than one-half of the basic seven-day mission limit. Actually, the crewmen are expected to work close to their productive potential during the limited periods of construction.

CONSTRUCTION SUMMARY



UNCERTAINTIES

The point is, that we have a "paper" estimate of what it may take to construct a possible platform. With the scarcity of experience and data available to such studies, it is foolhardy to project confidence that the three flight missions previously presented could perform the platform's construction as described.

We recognize two kinds of uncertainties in our ability to estimate construction requirements. The first is our current inability to accurately estimate for the factors shown as "design margin." Although we allowed 50% over our nominal estimates (conservatively estimated, we believe), we may, in fact, be grossly underestimating and ignoring many detailed activities which only future experience will illuminate.

In the second category, "contingency margin", we note that no specific allowance has been made for potential failures or anomalies in the hardware, software, or crew operations. As examples, no specific allowances have been made to deal with failures/repairs of the beam machine or the RMS. Several approaches are available to this type of problem: (1) provide increased redundancy and backup modes at the component and end item levels; (2) provide increased design margins, operate hardware at de-rated limits, and emphasize testing at all levels; (3) in connection with the above, plan for heavy front-end (R&D) costs and schedule subsequent time to shake out the potential problems.

BUT......
what about uncertainties?

UNCERTAINTY	CONSIDERATIONS	USED	MAY BE
DESIGN MARGIN	• CREW TIME • TRANSLATION TIME • PROCESS TIME • LIGHTING POWER • PROCESS POWER • PKG DENSITY	50%	> 100%
CONTINGENCY MARGIN	• REDUNDANCY • TESTING • FRONT-END COSTS	0%	>> 0%

CONSTRUCTION DEVELOPMENT

The following series of charts regard the R&D activities required to achieve and verify the requisite technology and to construct a platform of the ETVP.

CONSTRUCTION DEVELOPMENT

CONSTRUCTION TECHNOLOGY

The major technology developments required to support space construction, as described here, have been detailed in Rockwell Report SSD 80-0039 dated April 1980.

In general, these technology items constitute a category of critical issues which demand additional investigation/data as a prerequisite to a program start decision.

CONSTRUCTION TECHNOLOGY

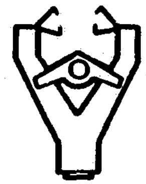
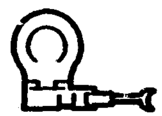
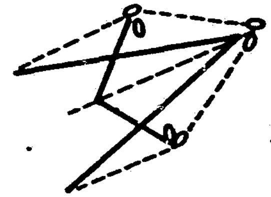
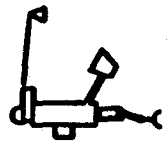
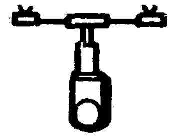
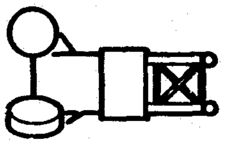
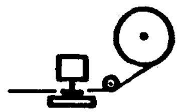
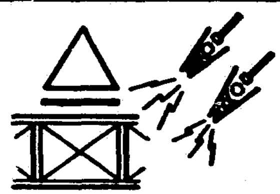
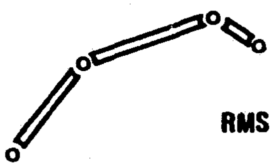
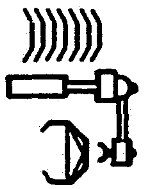
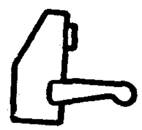
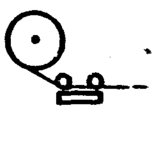
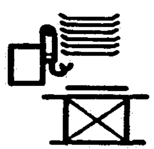
EQUIPMENT AND MATERIAL

- BEAM-TO-BEAM JOINTS—DEVELOP JOINT MATERIAL COMPATIBLE WITH BEAM MATERIAL; DEVELOP METHOD OF JOINT ASSEMBLY
- ROTARY ELECTRICAL TRANSFER JOINT—DEVELOP DESIGN FOR 64-kW POWER TRANSFER WITH MAINTENANCE/SERVICING PROVISIONS
- POWER & DATA ELECTRICAL CONNECTORS—DEVELOP CONNECTOR DESIGNS TO PROVIDE FOR EVA MAKE/BREAK CAPABILITY & TO ACCEPT AUTOMATIC MATING/DEMATING
- SWITCH GEAR—DEVELOP SWITCHES FOR 35-kW POWER TRANSFER IN SPACE ENVIRONMENT
- MATERIAL (COMPOSITE)—DEVELOP COMPOSITE MATERIAL HAVING LOW THERMAL COEFFICIENT, GOOD STRENGTH, AND EASE OF FABRICATION
- COMPOSITE STRUCTURE FOR FIXTURE—DEVELOP COMPOSITE MATERIAL AND FAB METHODS PROVIDING MAXIMUM DIMENSIONAL STABILITY DURING ON-ORBIT OPERATIONS
- PRESSURE SUIT (8 psi)—DEVELOP 8-psi PRESSURE SUIT FOR EVA CONSTRUCTION OPERATIONS WITH MAXIMUM MOBILITY, MAX VISION, DAMAGE-RESISTANT, ETC.
- SOFTWARE—CONTROL FOR OPERATION FROM ORBITER AND MRWS
  —COLLISION AVOIDANCE

CONSTRUCTION SUPPORT EQUIPMENT

Summarized here - in cartoon form - are the various items of construction support equipment needed to build the platform as previously described. The following discussion presents additional detail on several of the items which are currently in various stages of development.

CONSTRUCTION SUPPORT EQUIPMENT

 MAIN FIXTURE RETENTION DEVICE TRANSLATION MECH UNTENDED OPS EQUIP	 POSITIONING ARM (EVA)	 DIAGONAL CORD INSTALLER AND CORD TENSIONING TOOL
 CONSTRUCTION BERTHING PLATFORM	 MRWS	 BEAM POSITIONER
 SPACE FAB BEAM BUILDER	 CROSS BEAM HARNESS INSTALLER	 BEAM JOINER
 RMS	 ATTACH PORT INSTALLER	 MMU (CONTINGENCY)
 LONGITUDINAL HARNESS INSTALLER	 INTERSECTION FITTING INSTALLER	 LIGHTS AND VIDEO

CONSTRUCTION SUPPORT EQUIPMENT MODIFICATIONS

The automatic beam builder machine defined for this study is a derivation of the General Dynamics design. The construction concept requires special latches for use of the beam builder in the two construction stations, and requires modifications of the baseline software to provide for variable spacing of the beam's posts. Software is also required for special end configurations on transverse beams and crossbeams. Other modifications include thicker cap materials, heavier cross-brace cords, and packaging allowance for pre-installed Velcro strips on selected beam posts.

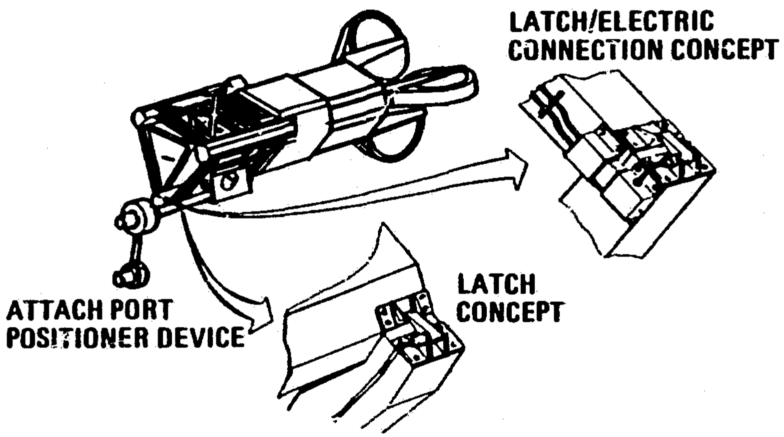
Modifications to the Grumman cherry picker include an active stabilizer arm and the capability of reconfiguration between missions. The control/display panel must also be used to control the positioning arm on the first mission. The positioning arm is a new requirement to facilitate maneuvering within the confined space of the tri-beam platform.

The standard RMS must be modified to include an upper-arm roll joint and associated software. The new mobility capability is considered to be of fundamental importance for space construction and highly useful for transfer of payloads to potential on-orbit stations.

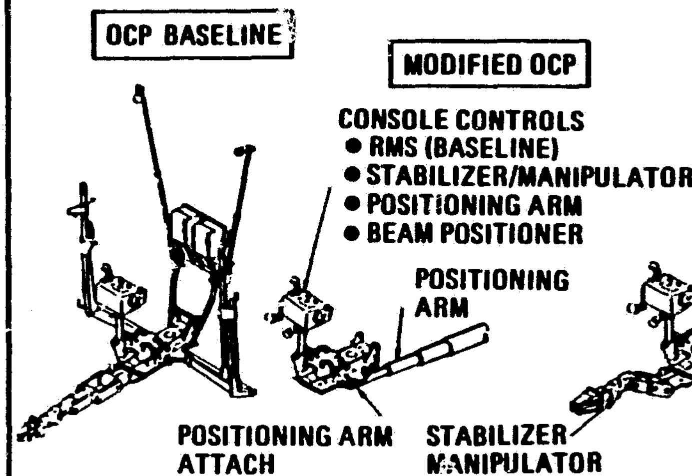
Certain software changes are essential for implementing the construction RMS. In particular, collison-avoidance warning signals and/or disabling signals are required for operational safety in handling large modules, struts, and beams in the vicinity of the construction stations.

The baseline grappling end-effector will have a number of uses in the construction operations; e.g., grasping and moving the beam machine from one location to another. There will be, however, a larger range of applications necessitating new designs (some of which may be adapted to the basic end-effector) to perform precision operations with small elements and to interface with fragile structural members.

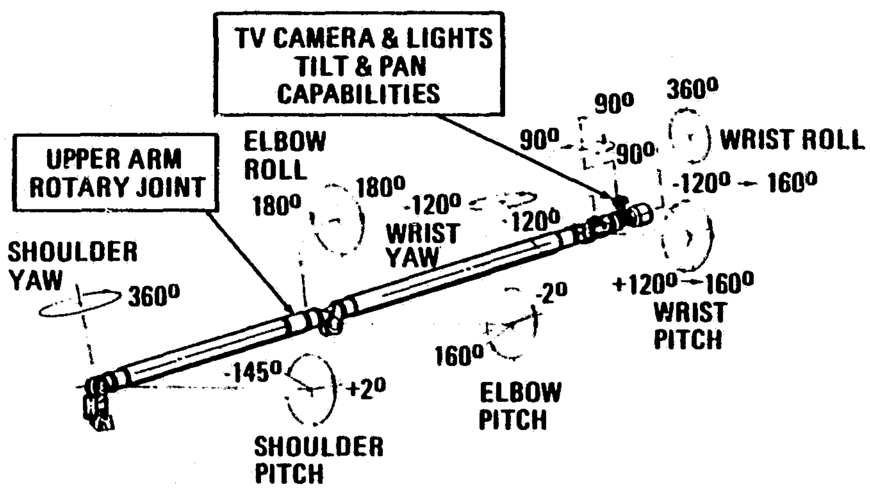
CONSTRUCTION SUPPORT EQUIPMENT MODIFICATIONS



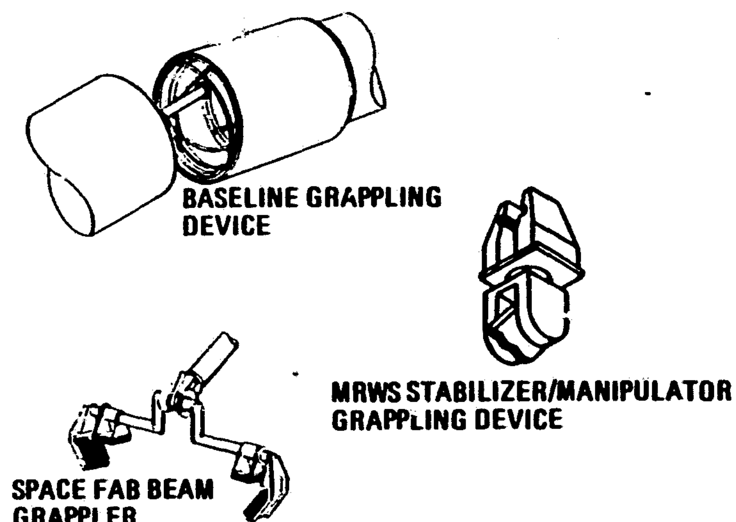
BEAM BUILDER



MANNED REMOTE WORK STATION (MRWS)



ORBITER REMOTE MANIPULATOR SYSTEM (RMS)



END EFFECTORS

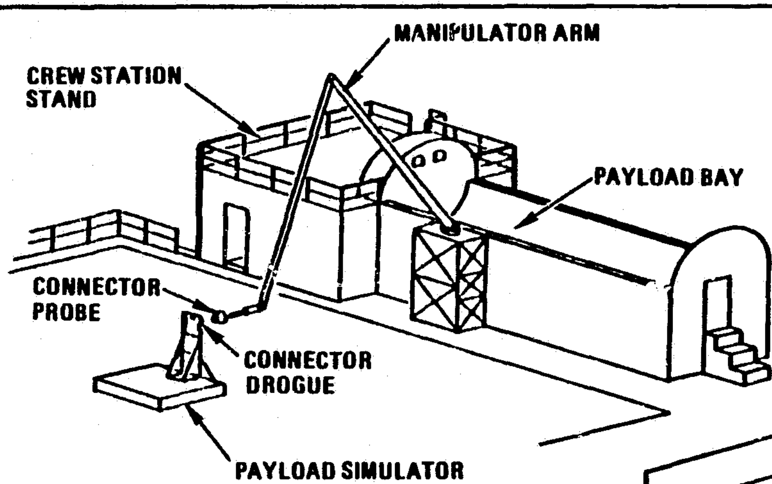
GROUND TEST PROGRAM

A great many technical issues will be effectively resolved through ground testing - and facilities at JSC, MSFC, and other agencies can provide simulated operational conditions for the development of construction methods and associated support equipment.

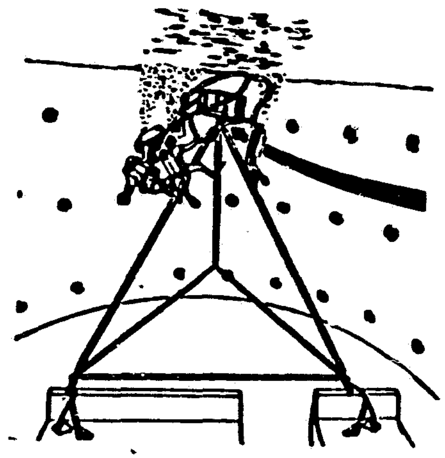
In general, it is our view that ground testing in existing facilities will provide most of the needed answers to the key technology and development questions.

Aerospace experience, however, teaches us that until hardware, software, and crew come together in the actual flight environment, we cannot be confident that the integrated effects of the technologies will be as predicted. Indeed, integrated systems testing has frequently driven out the most challenging of the technology issues. Thus, the next chart presents a series of possible flight experiments conceived as a time-phased program to develop and verify the integrated effects of the technologies needed to support future space construction programs.

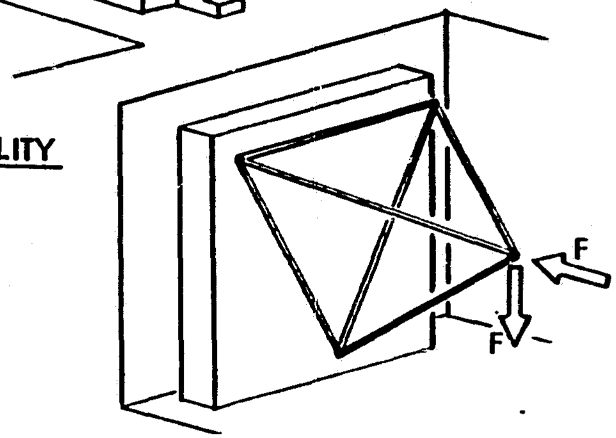
GROUND TEST PROGRAM



MANIPULATOR DEVELOPMENT FACILITY



NEUTRAL BUOYANCY SIMULATOR



STRUCTURAL LAB

- BEAM JOINING
- CHERRY PICKER/CONTROL
- END EFFECTORS
- SYSTEMS INSTALLATIONS
- MECHANISMS
- EVA OPERATIONS

FLIGHT EXPERIMENT PROGRAM

These five flight experiment concepts which, in conjunction with the ground test program, could generate the technology base needed to support future space construction programs.

The earliest experiment was conceived as a "suitcase" test to verify the use of the RMS to deploy a structural subassembly, to effect multi-point attachment of the structure, and to install a simulated equipment module. The experiment would also verify the ground-derived structural/dynamic identification of the assembly.

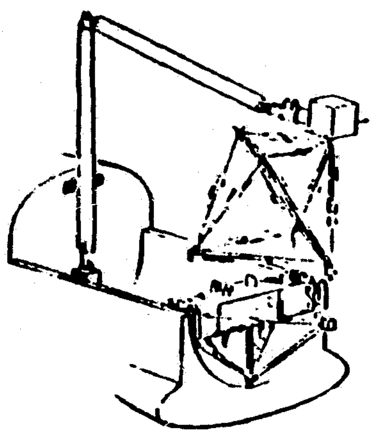
A subsequent experiment (lower, middle diagram) would further verify the use of EVA and support equipment (e.g., cherry picker, handling and positioning aid) to access a structure for the installation of lines and systems.

A later space-fabrication experiment would verify the performance of the beam machine and joining operations.

The upper middle diagram is a concept for verifying the deployment and identification of a boom which could replicate the dynamic performance of an antenna feed mast or of a slender structure such as a flexible platform or a space crane. This experiment would also explore the control authority of the orbiter during large mass/inertial transients.

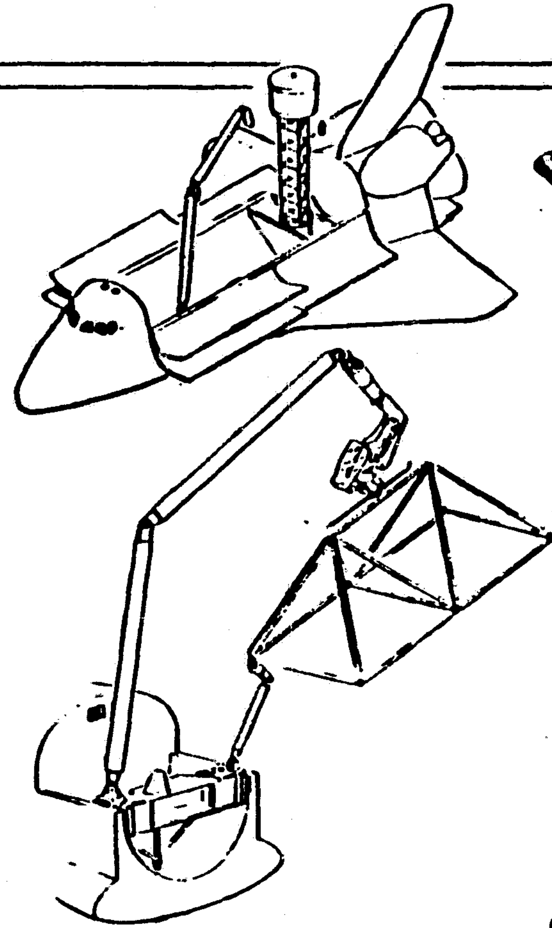
The large (50-100 m) deployable antenna experiment would verify the deployment (and retraction) of a complex structure, advanced controls for precision pointing, and orbiter-antenna dynamic interactions.

FLIGHT EXPERIMENT PROGRAM



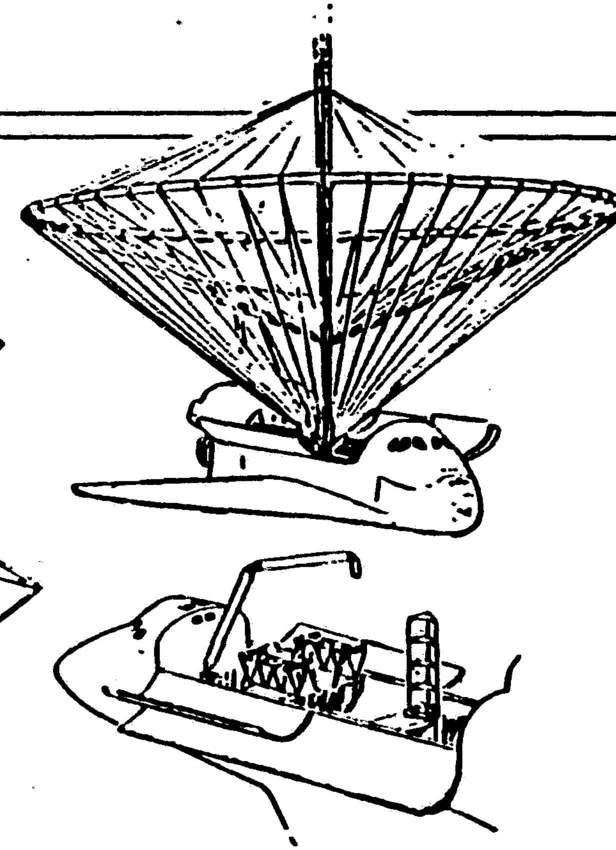
≈1983

- Deployable Structure
- Structural Dynamics
- Construction Operations



≈1984-1985

- Deployable Boom
- Structural Dynamics
- Adv. Controls
- Construction Equipment
- Construction Operations



≈1986

- Deployable Antenna Structure
- Str. Dyn. / Contr. Interaction
- RF Platform
- Space Fabrication
- Beam Joining
- Construction Equipment
- Construction Operations

ETVP COST AND PROGRAMMATICS

A summary of the resources needed to develop and construct the model (Engineering/ Technology Verification) platform is presented.

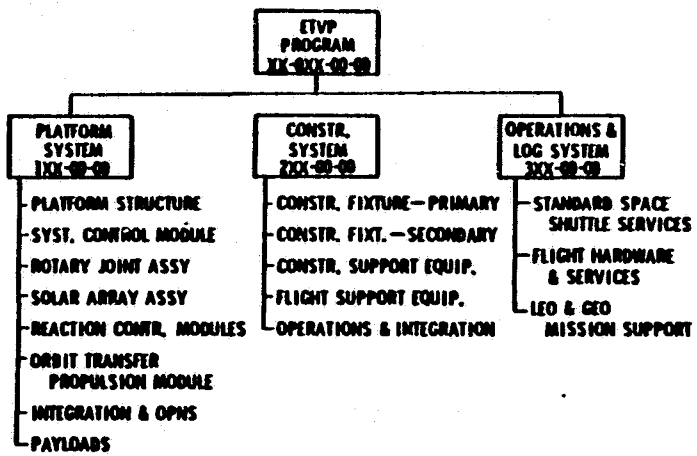
The cost breakdown of the program from authorization to IOC (start of low orbit testing) is shown in the lower left hand graph, and corresponds identically to the WBS elements shown directly above. These costs estimates have been generated from Rockwell's CER's and are detailed in Rockwell Report SSD 80-0039, SCSA Part 2 Final Report, Cost and Programmatics. The DDT&E costs include all ETVP unique engineering development charges beyond program start, and do not include the previously described technology-oriented ground and flight experiments.

It is noted that the platform flight hardware/software is the largest cost category - with the platform's front end (control module/solar array) comprising more than one-half the cost. It should also be noted that the orbit transfer propulsion modules, which are installed beyond the low-orbit test phase, have not been included in these charges.

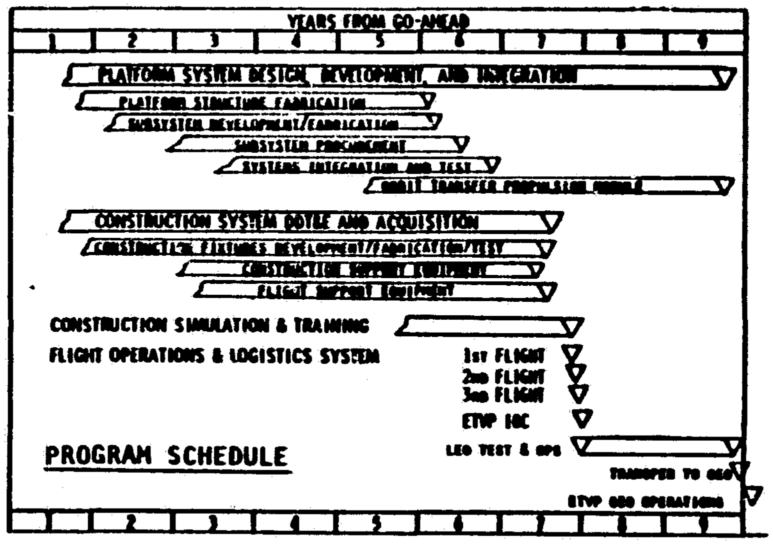
The construction system charges are about one-third of the program costs. This fraction would have been much larger had we applied typical flight system CER's to the estimates. However, we have assumed that this type of hardware would be engineered more along the lines of factory equipment rather than flight systems. The relatively large systems engineering component represents the influence of construction software development.

It may also be noted that the launch and operations costs were only one-sixth of the program; this might suggest that trades could be warranted to cut costs in the other categories at the expense of additional flights.

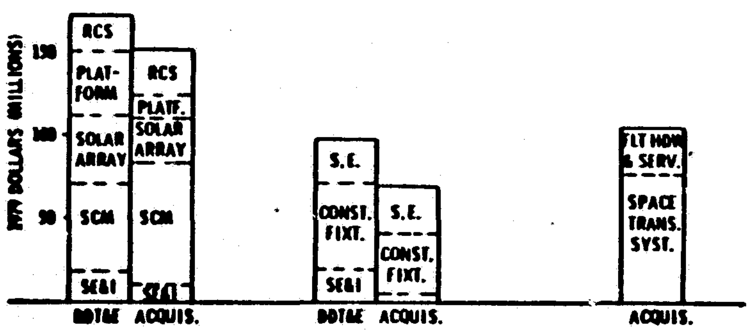
ETVP COST AND PROGRAMMATICS



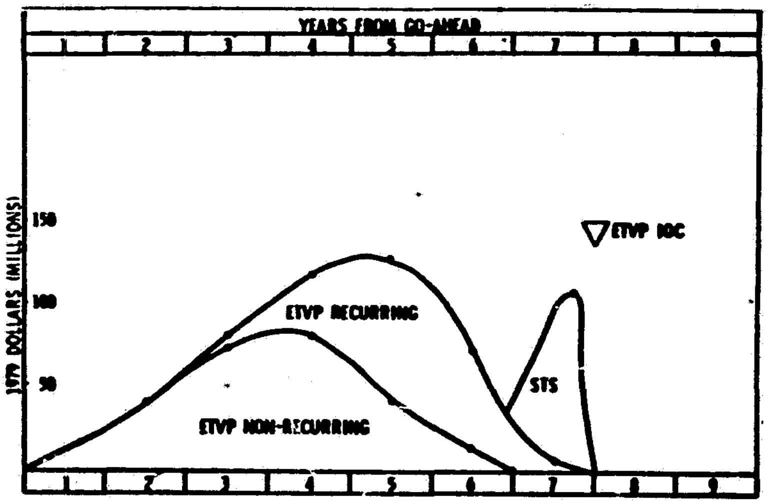
WORK BREAKDOWN STRUCTURE



PROGRAM SCHEDULE



COSTING



FUNDING

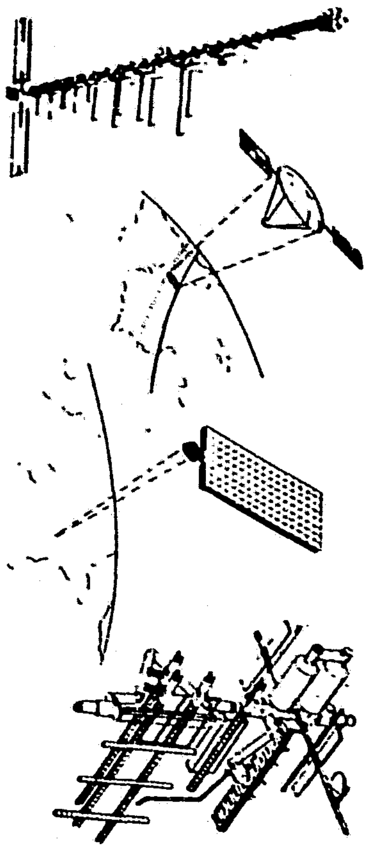
No text required.

CONCLUSIONS
AND
RECOMMENDATIONS

No text required.

CONCLUSION

☆ WE KNOW THAT SPACE CONSTRUCTION & ASSEMBLY MUST HAPPEN BECAUSE -

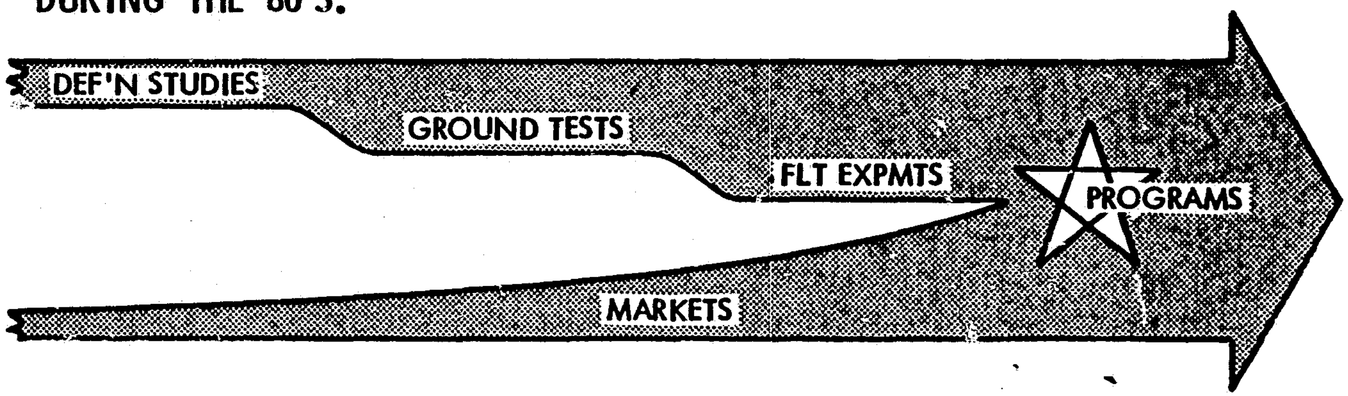


- OUR APPETITE FOR COMMUNICATIONS WILL OUTSTRIP PHYSICAL RESOURCES (ORBITAL ARC AND FREQUENCY SPECTRUM)
- WE NEED FINER DETAIL - ON A GLOBAL BASIS - OF THE EARTH, IT'S OCEANS AND ATMOSPHERE - AND MAN'S WORKS
- SPACE - GENERATED POWER MAY BE REQUIRED TO COMPLEMENT LIMITED ENERGY RESOURCES
- MAN'S PRESENCE IN SPACE WILL BECOME NECESSARY TO THE NATION'S ECONOMIC, SCIENTIFIC, AND MILITARY FUTURE

No text required.

CONCLUSIONS (CONT)

☆ TWO INGREDIENTS ARE PRE-REQUISITE TO MAKE THOSE THINGS HAPPEN: TECHNOLOGY AND MARKETS. WE BELIEVE THESE THINGS WILL MERGE DURING THE 80'S.

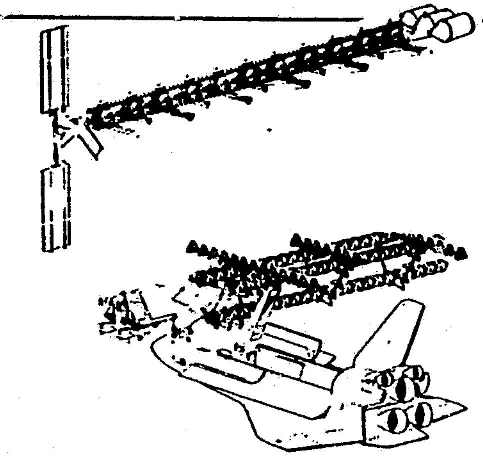


☆ ON THE TECHNOLOGY SIDE, THIS STUDY HAS SHOWN THAT CONSTRUCTION OF LARGE SPACE - FABRICATED SYSTEMS IS PRACTICABLE WITHIN THE 80'S.

☆ THE STUDY HAS DRIVEN OUT THE TECHNOLOGY NEEDS WHICH SHOULD BE TARGETED DURING THE EARLY 80'S.

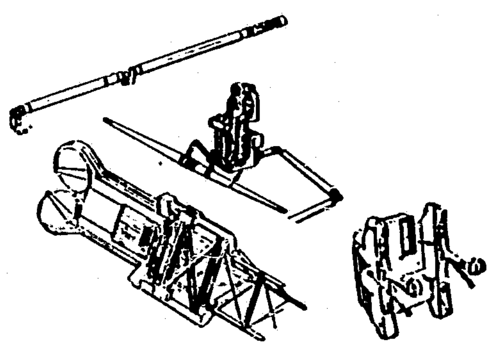
No text required.

CONCLUSIONS (CONT)



☆ WE HAVE SHOWN THAT LARGE SPACE SYSTEMS SHOULD:

- BE DESIGNED BY SPACE CONSTRUCTION
- BE CONSTRUCTED BY AUTOMATED SYSTEMS - AUGMENTED BY EVA



☆ WE HAVE FURTHER CONCLUDED THAT:

- ON-GOING NASA DEVELOPMENTS (E.G., CHERRY PICKER, SUITS) ARE ESSENTIAL - AND THAT CONSTRUCTION REQUIREMENTS SHOULD BE INCORPORATED

BUT......
what about uncertainties?

UNCERTAINTY	CONSIDERATIONS	USED	MAY BE
DESIGN MARGIN	• CREW TIME • TRANSLATION TIME • PROCESS TIME • LIGHTING POWER • PROCESS POWER • PKG DENSITY	[illegible]	> [illegible]
CONTINGENCY MARGIN	• REDUNDANCY • TESTING • FRONT-END COSTS	[illegible]	>> [illegible]

- UNCERTAINTIES IN SPACE CONSTRUCTION ANALYSIS MUST BE RESOLVED BY EARLY GROUND TESTS AND FLIGHT EXPERIMENTS

RECOMMENDATIONS

This study has provided an improved understanding of the technology needs and developments required to support potential large space system programs of the future.

As NASA continues its on-going development of elements which could play critical roles in space construction, consideration should be given to some of the requirements identified herein.

This study has superficially skimmed the top of the large issue of controls and software for construction. This potentially large-cost item needs significant attention in future studies of space construction.

We have indicated that design and contingency margins are among the largest uncertainties in the planning/estimating of space construction. It is appropriate that special sensitivity analyses be performed to generate a basis for such allowances.

The particular construction fixture and platform structural arrangement of this study might be simplified - at the expense of additional launch/operations costs. We suggest that future studies compare other arrangements on a program cost basis.

This study has clearly indicated that installation of systems (lines, blankets, components, modules) is the major driver in the construction process. We suggest that increased emphasis be given to ground testing of attachment hardware, methods, and support equipment.

With Shuttle launch opportunities rapidly being allocated (competition will become especially severe after first flight), it is imperative that early flight experiments be planned and allocated - if we are to have the needed technology base by the mid/late 80's.

RECOMMENDATIONS

- ☆ INTEGRATE CONSTRUCTION REQUIREMENTS INTO CONTINUING DEVELOPMENT OF RMS, EFFECTORS, CHERRY PICKER, EVA SUIT
- ☆ CONTROLS/SOFTWARE REQUIREMENTS AND APPROACH SHOULD BE DEFINED
- ☆ GENERATE CRITERIA AND APPROACHES FOR CONSTRUCTION DESIGN AND CONTINGENCY MARGINS
- ☆ CONSIDER ALTERNATIVE FIXTURE/CONFIGURATION CONCEPTS IN TERMS OF FIRST-COST AND RE-USE
- ☆ INCREASE THE EMPHASIS ON INSTALLATION OF SYSTEMS AND GROUND TESTING
- ☆ WE NEED TO MOVE OFF WITH THE EARLY FLIGHT EXPERIMENTS - GET THE APPROVALS AND THE FUNDING